AN ABSTRACT OF THE THESIS OF

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Title: STRATIGRAPHY AND SEDIMENTOLOGY OF THE CRETACEOUS NANAIMO GROUP, SALTSPRING ISLAND, BRITISH COLUMBIA

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Clastic sedimentary rocks of the Nanaimo Group on Saltspring Island, British Columbia are Late Cretaceous in age, overlie a deformed and intruded Paleozoic basement complex, and consist of eight formations. These eight formations, from oldest to youngest, are the Comox, Haslam, Extension-Protection, Cedar District, De Courcy, Northumberland, Geoffrey, and Spray Formations. The Formations vary greatly in thickness, consist of multiple members, and show complex intertonguing relationships. A composite section of minimum thickness totals approximately 9,000 feet.

In the study area, the Nanaimo Group is tentatively divided into two subgroups, the lower Nanaimo Group - Comox through Extension-Protection Formations - and upper Nanaimo Group - Cedar District through Spray Formations. The lower Nanaimo Group consists of a series of three transgressive sequences, each of which overlies an erosional surface and shows an upward-fining of grain size and

progression from nonmarine or nearshore marine to offshore marine deposition. The upper Nanaimo Group can be divided into a total of five progradational cycles which show upward-coarsening from prodelta mudstone to delta-front sandstone, and locally to fluvial-marine channel conglomerate. Prodelta muds were probably deposited at lower neritic to upper bathyal water depths.

The Comox Formation was deposited as a delta or fan delta with a braided fluvial system and flanking littoral sandstones including beaches which contain heavy mineral placers and tidal creek channels. The Extension-Protection Formation was deposited along a piedmont plain with laterally contiguous marine turbidites. The Cedar District and De Courcy Formations intertongue through a stratigraphic interval of at least three thousand feet. Four Cedar District to De Courcy progradational cycles are characterized by an upward progression from offshore marine mudstone and distal turbidite to proximal turbidite or/and fluidized sediment flow and locally to a laminated and cross-bedded sandstone and channelized conglomerate lithofacies. The sequences are indicative of repeated superposition of prodelta, delta-front slope, and fluvial-marine environments of deposition. The Northumberland and overlying Geoffrey Formation comprise a very thick progradational sequence complete with a thick and extensive conglomeratic interval in the Geoffrey Formation.

Mineralogy and Paleocurrent data of the Comox Formation suggest derivation from low to intermediate grade metamorphic and intermediate to basic igneous rocks located a short distance to the southwest. The overlying sandstone-conglomerate formations record a decreased contribution from metamorphic and basic igneous rocks and increased contribution from intermediate to silicic plutonics and volcanics. De Courcy paleocurrent data suggest derivation from the east: sandstone compositions indicate the major source was an uplifted region of intermediate plutonic rocks which was rapidly eroded and subject to mainly mechanical weathering. The Geoffrey Formation shows an abrupt increase in intermediate to silicic volcanic debris possibly derived from the Bonanza Volcanics located to the south and southwest on Vancouver Island.

Post-depositional mineralogic changes include widespread cementation by calcite, laumontite, and quartz. The assemblage laumontite plus prehnite is locally developed in the Comox Formation. Laumontite occurs in all overlying sandstone formations. A green diagenetic matrix was derived from the in situ alteration of volcanic rock fragments and is particularly abundant in the Geoffrey Formation.

Tertiary faulting and folding of the study area formed the Kulleet Syncline, Trincomali Anticline, a system of northwest-trending strike faults and a system of north-trending transverse faults.

Stratigraphy and Sedimentology of the Cretaceous Nanaimo Group, Saltspring Island, British Columbia

by

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INTRODUCTION

Location and Accessibility

The area of investigation is located in southwestern British Columbia, 25 to 40 miles north of the provincial capitol of Victoria. Saltspring Island is a member of the Gulf Islands and served by ferry from Crofton and Sidney on Vancouver Island and Tsawwassen on the mainland. It is separated from Vancouver Island on the west by Sansum Narrows, bounded on the east by Trincomali Channel and buffered from the Strait of Georgia by the outer Gulf Islands (Figure 1). To the south lies Sannich Peninsula and to the north are Houston Passage and Kuper Island. An extensive all-weather road network and four small communities, Ganges, Fulford, Vesuvius and Fernwood, exist in the central and northern parts of the island. In addition, numerous new homes and subdivision sites line the northwest coast and Ganges Harbor.

Excellent exposures of bedrock exist along the deeply indented perimeter of the island. Bedrock consists of metamorphosed Late Paleozoic igneous and sedimentary rocks and Late Cretaceous sedimentary rocks of the Nanaimo Group. The Nanaimo Group underlies about half of the island's 77 square miles. Important coastal geographic

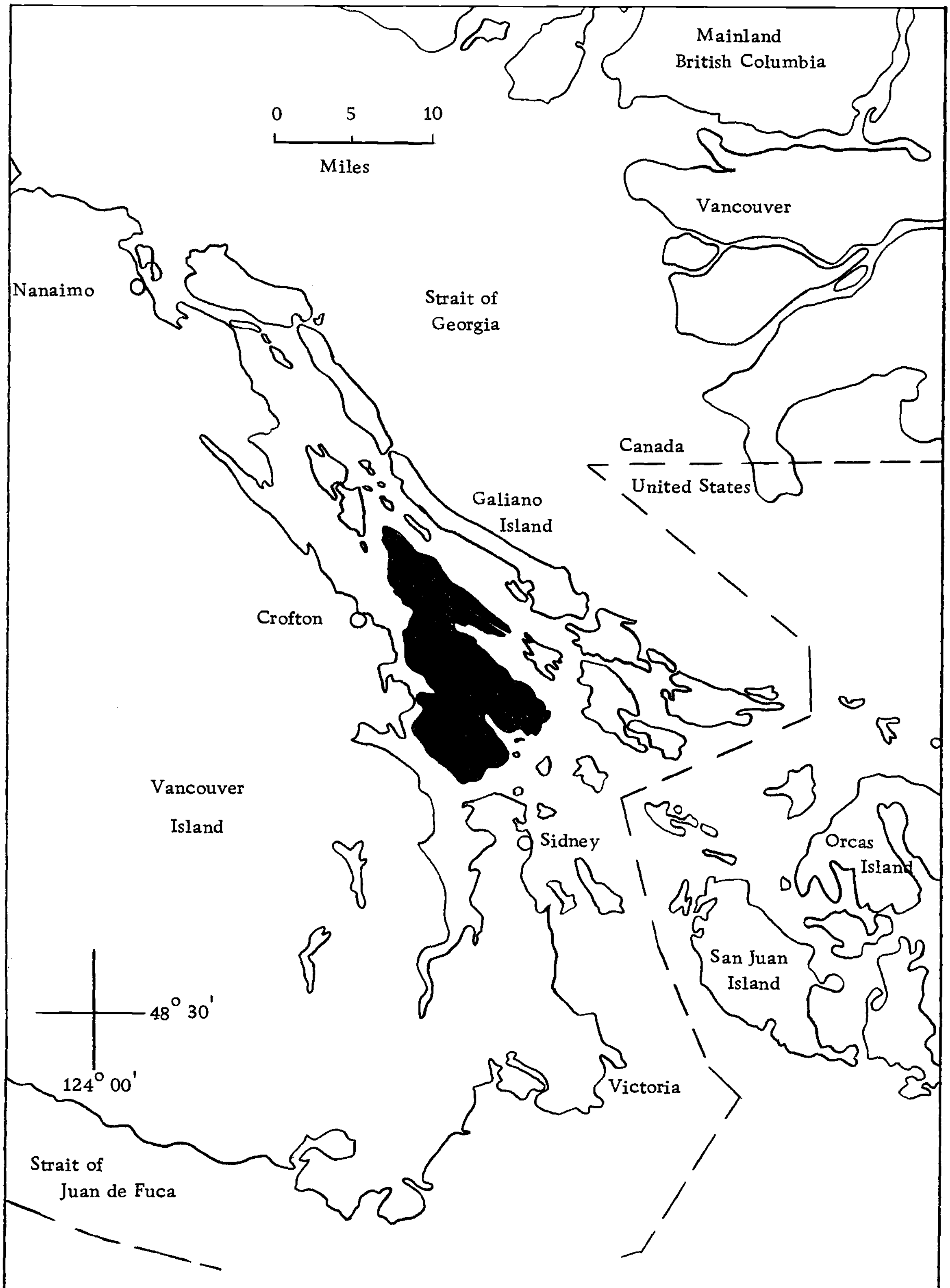


Figure 1. Index map showing location of study area.

features include (Plate 1): Southey Point, Stone Cutters Bay, Dock Point, Vesuvius Bay, Booth Bay, and Erskine Point on the northwest coast; Fernwood Point, Walker Hook, Athol Peninsula, Long Harbor, Scott Point, Welbury Point, and Ganges Harbor on the northeast coast; and Yeo Point Beaver Point, Eleanor Point, Fulford Harbor, Isabella Point, Cape Keppel, Musgrave Point, and Burgoyne Bay on the south coast.

Inland away from the shoreline, the more resistant cliff- and cuesta-forming rock bodies are exposed. Major topographic features include Bruce Peak (2300 feet), Mount Tuam (2000 feet), Reginald Hill (800 feet), and Lake Weston (200 feet) on the south half of the island; Mount Maxwell Provincial Park (2000 feet), Lake Maxwell (1025 feet), Cusheon Lake (300 feet), Mount Erskine (1450 feet), and St. Mary Lake (150 feet) occur on the north half of the island.

The Gulf Islands are subject to mild temperature conditions, moderate rainfall (about 40 inches annually), and a short summer drought. Vegetation covers much of Saltspring Island. Forests are of the Douglas-fir type (Pseudotsuga menziesii) and include large stands of Madrone (Arbutus menziesii) and lesser amounts of western red cedar (Thuja plicata), red alder (Alnus rubra), bigleaf maple (Acer macrophyllun), and a ground cover dominated by salal (Gaultheria shallon). A mixed forest of lodgepole pine (Pinus contorta) and stunted Douglas-fir exists on Mount Erskine. Bedrock surfaces are

Figure 2. Looking northwest at southern and central parts of Saltspring Island from Haro Strait near the International Boundary. Prominent topographic features are Mount Tuam (T), Bruce Peak (Br), Reginald Hill (R), Mount Maxwell (M), and Mount Belcher (B).

populated by mosses, grasses, lichen, succulents (*Sedum*) and, near Eleanor Point, prickly pear cactus (*Opuntia*).

Purposes of Investigation

Major objectives of this study are to: (1) determine the structure and areal distribution of the Nanaimo Group in the study area; (2) describe the lithologies, thicknesses, and lateral variations within the Nanaimo Group; (3) delineate Late Cretaceous sediment transport directions; (4) reconstruct Late Cretaceous depositional environments and depositional systems and their relationships in time and space; (5) determine mineralogy of the Nanaimo Group and draw conclusions as to provenance and post-depositional history.

Historical Development of Nanaimo Basin Stratigraphy

The Nanimo Group has been studied for more than a century. Early work was directed at evaluation and exploitation of coal fields at Nanimo and Comox on Vancouver Island. With the decline of coal mining in the mid-twentieth century, publications have become concerned with regional stratigraphic and biochronologic synthesis and delineation of depositional environments. Following is a partial listing of contributions to knowledge of the Cretaceous of the Nanaimo Basin and Saltspring Island. A good chronological summary of early work can be found in the work of Usher (1952).

1852: Coal is first mined at Nanaimo by Hudson's Bay company under the name of Nanaimo Coal Company (Clapp, 1914).

1857: Cretaceous age of the coal-bearing rocks is first determined by a study of plant fossils collected at Nanaimo and Orcas Island. This is the first known occurrence of Cretaceous rocks on the western coast of North America (Newberry, 1857 in: Usher, 1952).

1860: Cretaceous age of the Nanaimo sequence is confirmed on the basis of Inoceramus and cephalopods, although the author believes (as a result of incorrect identification of plant fossils (Lesquereux, 1859)) that the Gulf Islands are underlain by Tertiary strata (Bauermann, 1860).

1861: Hector relates observations made during a canoe trip of 70 miles along the east coast of Vancouver Island during which he is guided by four natives. He notes that "clay-shales" on the northeastern coast of "Salt Spring Island" underlie the best land for settlement that he has seen on the coast.

1872: A geologic map of Nanaimo and Comox coal fields is published by the Geological Survey of Canada. The gross outline of Cretaceous rocks on Saltspring Island is accurate with the exception of the Mount Maxwell area (Richardson, 1872).

1878: Richardson adopts a seven-fold subdivision of the coal-bearing section and traces his oldest unit, "Productive Coal Measures," southeast of Nanaimo for 61 miles. He maps all of the Saltspring Island Cretaceous as "Productive Coal Measures," notes thin coals at Vesuvius Bay, mudstone and overlying conglomerate near Erskine Point (now Haslam and Extension-Protection Formations, respectively), believes mudstone overlying the conglomerate (now lower Cedar District Formation) is a repetition of the underlying mudstone, and that mudstone of Duck Bay and overlying sandstone and conglomerate (now Northumberland and Geoffrey Formations, respectively) are again a repetition of the sequence near Erskine Point Richardson, 1878).

1890: The Nanaimo Group is formally named as such and correlated in part with the Chico Group of California. Dawson recognizes the conformable nature of stratigraphic units which overlie the Nanaimo coal measures (Dawson, 1890).

1912-
1917: Geologic maps of southeastern Vancouver Island, including the pre-Nanaimo Group basement, are published. The extensive work of Clapp includes recognition, naming and description of 11 lithostratigraphic units in the Nanaimo area, recognition of considerable relief on the basement, abrupt lateral facies changes, difficulty of correlation, and that the sequence in the Saturna-Mayne-Galiano area is twice as thick as at Nanaimo

(Clapp, 1912, 1914; Clapp and Cook, 1917).

1927: Marine and deltaic strata of Late Cretaceous age are mapped on Sucia, Waldron and Skipjack Islands of the San Juan Islands. Beds called the Chuckanut Formation in northwestern Washington are considered to include continental equivalents of the upper part of the Nanaimo Group (McLellan, 1927).

1947: Buckham restudies the Nanaimo coal field, describes 7,600 feet of section and emphasizes the structure as a zone, west of Nanaimo, of northwest-trending thrust faults (Buckham, 1947).

1952: Usher describes in detail ammonite faunas of the Nanaimo Group and establishes a biochronologic zonation. His work includes lithologic descriptions of formations (essentially a refinement of those of Clapp) and faunal collections at four localities on Saltspring Island.

1957: Study of Nanaimo Group flora suggests a warm temperate climate (Bell, 1957).

1963: Supposed Tertiary units in the vicinity of the city of Vancouver are shown to be correlative with the Vancouver Island Cretaceous on the basis of fossil leaf-floras. Microfloral analysis independently confirms regional correlations based upon molluscan faunas and indicates that a Late Cretaceous to Paleocene basin extended widely over Vancouver Island, the southwestern mainland of British Columbia (for at least 60 miles up the Fraser River Valley), and for an unknown distance into Washington State east of Bellingham (Crickmay and Pocock, 1963).

1964: Zonation of the Nanaimo Group on the basis of foraminifera shows that (as did Usher's work) deposition commenced in the Nanaimo Basin prior to deposition in the Comox Basin. Collections were made at five localities on Saltspring Island (McGugan, 1964).

1967-
1971: Geological Survey of Canada geologists, J. E. Muller and J. A. Jeletzky, standardize lithostratigraphic nomenclature (nine formations), develop a biostratigraphic zonation on the basis of ammonite and Inoceramus faunas, and publish a 1:250,000 map of the areal distribution of the formations. The Nanaimo Group is interpreted as a series of four transgressive cycles which show a progression from fluvial to deltaic and/or lagoonal, to nearshore marine and offshore marine deposition (Muller, 1967; Muller and Jeletzky, 1967; 1970; Muller and Atchison, 1971).

1971-
1975: Oregon State University students, under the direction of Dr. Keith F. Oles, undertake mapping and stratigraphic studies in the Gulf Islands. Several M. S. theses are completed and furnish detailed lithostratigraphic information and paleocurrent data (Packard, 1971; Rinne, 1971; Simmons, 1972; Hudson, 1974; Sturdavant, 1975).

REGIONAL GEOLOGIC SETTING

Basement Complex

The study area lies at the eastern margin of the Insular Belt tectonic province, the area located seaward from the present mainland coast of British Columbia to the continental slope (Sutherland-Brown, 1966). Regionally, the Nanaimo Group unconformably overlies a deformed and intruded geosynclinal assemblage which consists of the Permian and older Sicker Group and Triassic and Early Jurassic Vancouver Group, and also overlies Late Jurassic intrusions. The basement of Saltspring Island consists of a diverse and complex assemblage of metamorphic rocks belonging to the Sicker Group and associated Tyee Intrusion.

Sicker Group

Late Paleozoic rocks of Vancouver Island, the Sicker Group, are exposed in two major northwest-trending uplifts and are part of a metamorphosed Paleozoic-Mesozoic eugeosynclinal belt which extends southeast through the San Juan Islands and into the northern Cascade Mountains (Danner, 1957). The Sicker Group was named by Clapp and Cook (1917) for porphyritic andesites on Mount Sicker west of the thesis area and includes the oldest rocks known on Vancouver Island.

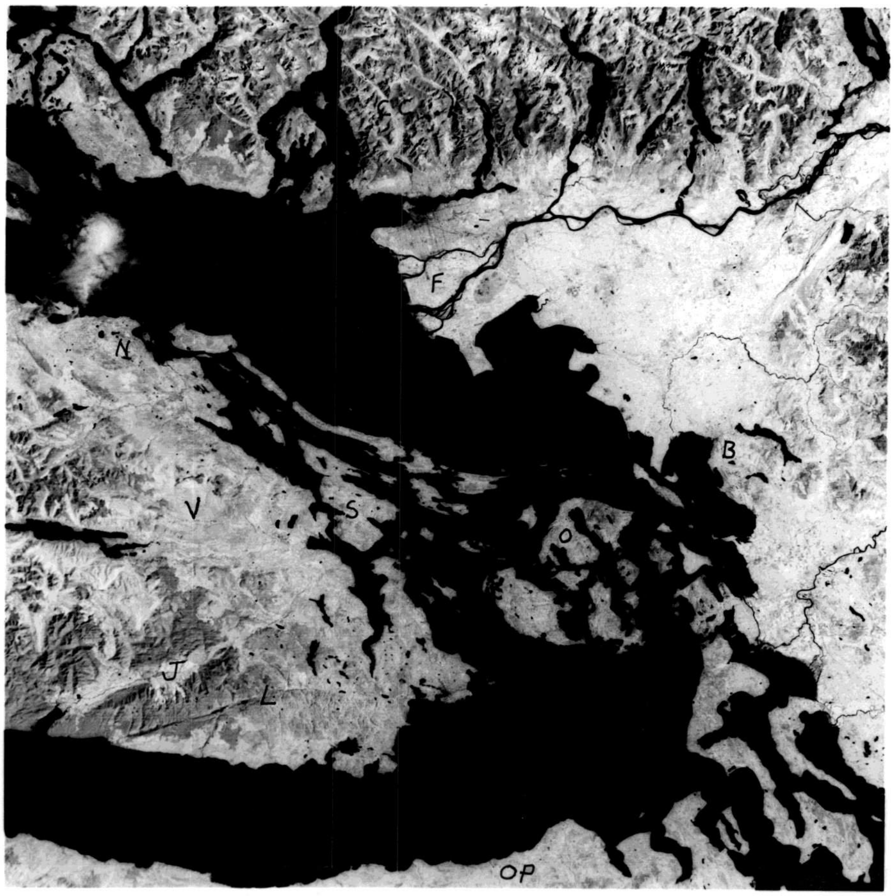


Figure 3. Earth Resources and Technology Satellite photograph showing regional setting of the study area; Saltspring Island (S), Vancouver Island (V), Olympic Peninsula (OP), Coast Crystalline Belt (CC) of mainland British Columbia, Bellingham, Washington (B). The Nanaimo Basin extends from Nanaimo (N) to Orcas Island (O) of the San Juan Islands. Also note the Fraser River Delta (F) which is prograding into the Strait of Georgia, and the San Juan (J) and Leech River (L) faults of southern Vancouver Island. Negative courtesy of EROS Data Center, Sioux Falls, South Dakota. ERTS Band 7 photograph taken July 30, 1972.

It consists of more than 10,000 feet of varyingly metamorphosed intermediate volcanics, sandstones, argillites, cherts, and limestones. A three-fold subdivision is possible (Muller and Carson, 1968). Thickest and most extensive is the lower metavolcanic division which is composed of greenstone, schist and phyllite. Many lavas are coarsely porphyritic with hornblende pseudomorphs after augite (Clapp and Cook, 1917). Secondary epidote and actinolite indicate a low greenschist metamorphic grade (Muller, 1975). A middle sedimentary division includes chert, argillite, sandstone and conglomerate and is intruded by diabase sills and glomeroporphyritic gabbro porphyries. (The latter are well known to local rock collectors as "flower stone.") An upper division of Pennsylvanian and early Permian cherty limestone occurs near Buttle Lake on Vancouver Island.

The lower metavolcanic and middle sedimentary divisions of the Sicker Group are present on Saltspring Island and comprise much of the basement. The rocks are part of a major uplift which extends northwest at least to Port Alberni.

The area between Beaver Point, Beaver Point Provincial Park, and Cusheon Cove is underlain by greenstone and greenschist. At Beaver Point, grayish green (10GY 5/2) to dusky yellow green (5GY 5/2) slightly foliated metavolcanics contain quartz veins and pods and epidote porphyroblasts. At the head of the cove on the north side of Beaver Point is a distinctive grayish green (10GY 5/2) altered dacite porphyry. The rock contains round and embayed quartz phenocrysts and stubby white and cloudy andesine phenocrysts in a translucent groundmass.

Sicker metasediments are exposed on the coastline 0.7 miles north-northwest of the Beaver Point light house on the south side of a sharp point, Section 57. Remnant sedimentary textures consist of medium to very coarse quartz sand grains and stretched pebbles and cobbles in a dusky yellow green (5GY 5/2), weathered, schistose matrix. Pyrite is locally abundant. Attitude of the schistosity is N. 68° W., 26° S.

At Erskine Point and south for at least a mile along the east shore of Sansum Narrows, several thousand feet of green metavolcanics are well-exposed. Unlike the sequence at Beaver Point, the Erskine Point sequence is well stratified and very thick-bedded. Beds dip steeply southwest and consist of grayish green altered porphyritic andesite, andesite porphyry, and light olive gray (5Y 5/2) weathered, porphyroblastic quartz-muscovite-chlorite schist. Many of the porphyries contain medium to coarse stubby hornblende phenocrysts. One of the beds which was examined petrographically consists of oligoclase and distinctive pale green hornblende phenocrysts with interstitial chlorite (and rare associated metamorphic biotite), aggregates of microcrystalline epidote, and leucoxene. Lithologies similar to those at Erskine Point underlie much of the area between the west end of Mount Maxwell Park and Erskine Point.

Most of the south lobe of Saltspring Island is underlain by low-grade metamorphic basement. A thick sequence similar to that at Erskine Point occurs in a band from Burgoyne Bay to Isabella Point. The steeply southwest-dipping schists, phyllites and greenstones locally contain manganiferous chert and rhodonite in association with cherty argillite and hematite-quartz schist. Black phyllite crops out along the gravel road (Musgrave Road) in Section 45, along the coastline east of Cape Keppel in the SW. 1/4 Section 32, and on the north side of Mount Tuam in the SW. 1/4 Section 38. The peninsula at Musgrave Landing is underlain by argillite and fine-grained meta-sandstone.

Several basic intrusions occur in the Sicker Group. Mount Tuam is underlain by grayish green medium to coarsely crystalline meta-gabbro (see Plate 1). The rock has a relict porphyritic texture of cataclastised labradorite phenocrysts (An 54) and an intergranular metamorphic assemblage of actinolite, epidote, chlorite, and calcite. Bruce Peak is held up by altered diabase. The body may be a sill of several hundred feet thickness. It contains abundant actinolite, epidote and chlorite and five percent exsolution intergrowth of magnetite and leucoxene. In the SE. 1/4 Section 43, small rounded knobs are underlain by dark greenish gray (5G 4/1), fresh, glomeroporphyritic gabbro-diorite. White radiating clusters of plagioclase attain one inch in diameter.

Tyee Intrusion

A group of rocks tentatively considered to be late Paleozoic granitic intrusions which affect only the Sicker Group, are referred to as the Tyee Intrusions (Muller, 1975). Tyee Intrusion rocks underlie about 10 square miles in the east half of the central part of Saltspring Island. They occur in the area from west of Beaver Point Provincial Park to the east side of Mount Maxwell Provincial Park and north to Cusheon Lake, also crop out along the north side of Fulford Harbor, and underlie Reginald Hill and isolated knobs at Eleanor Point. The main body possesses a rectangular joint pattern which is particularly distinctive on high-altitude photographs.

On Saltspring Island, the Tyee Intrusion is very light gray (N8) to light gray (N7), medium to coarsely crystalline altered granodiorite to quartz monzonite. It is locally slightly foliated (N. 60^{o} W.) and cut by aplite dikes (SW. 1/4 Section 76). A sample collected near Eleanor Point consists of thoroughly sericitized plagioclase (oligoclase to andesine), quartz, and micrographic quartz-orthoclase. Accessory minerals include biotite, hornblende, magnetite, and apatite. Sericite veins and joint coatings, chlorite, epidote and calcite are present.

Figure 4. Looking southwest from Baynes Peak at Fulford Harbor. Resistant Sicker Group metamorphics comprise the hills on the right. Granitic Tyee intrusion rocks underlie hills on the left.

Vancouver Group

The Vancouver Group includes all Triassic and Early Jurassic volcanic and sedimentary rocks of the Insular Belt. The Vancouver Group accumulated in an oceanic and island arc setting and consists of the Triassic Karmutsen Formation and Early to Middle Jurassic Bonanza Volcanics (Muller, 1971). The Karmutsen Formation, the most extensive rock unit on Vancouver Island, consists of a monotonous sequence, possibly 20,000 feet thick, of basalt flows, pillow lavas and breccias (Muller and Carson, 1969). The Bonanza Volcanics are typically dark reddish to greenish and white-weathering andesitic to dacitic tuffs and flows which contain hornblende and plagioclase feldspar phenocrysts. Vitrophyric rhyodacites also occur (Muller, 1971). The Bonanza Volcanics are less metamorphosed than the Sicker Group and are widely distributed to the south and west of the thesis area (Muller, 1975).

Vancouver Group volcanics are not recognized on Saltspring Island. However, the Mount Tuam and Bruce Peak intrusions resemble sills described elsewhere and are considered to be possible intrusive representatives of the Karmutsen Formation (Muller and Carson, 1969). The absence of Vancouver Group extrusives probably indicates that the area was emergent for a long interval prior to deposition of the Nanaimo Group.

Island Intrusions

A group of plutons called the Island Intrusions constitute the youngest major pre-Nanaimo Group rock unit on southern Vancouver Island. The intrusions are of Early to Late Jurassic age and consist of granodiorite and quartz diorite, minor quartz monzonite, diorite and gabbro, and rare granite (Carson, 1973). Included are the Nanaimo batholith, Alberni Inlet batholith, and Saanich Granodiorite. Granitic rocks of the study area are considered to be paleozoic in age. Radiometric dating is in progress (Muller, 1975).

Nanaimo Group

The Nanaimo Group is primarily confined to a narrow outcrop belt extending northwest from the San Juan Islands of Washington State, through the Gulf Islands of British Columbia, and along the east coast of Vancouver Island to Campbell River, a distance in excess of 150 miles. Strata of equivalent age exist on mainland British Columbia in the vincinity of Vancouver and Burrard Inlet (the Burrard formation) and east of Vancouver along the Fraser River (Crickmay and Pocock, 1963). The Burrard Formation is at least 2,000 feet thick and consists of coarse-grained, cross-bedded arkosic sandstone and conglomerate channels. The formation is nonmarine and was deposited on a piedmont plain (Johnston, 1923; Crickmay and Pocock, 1963).

The Santonian and Campanian stages also exist in the subsurface at the southern margin of the Fraser River delta (Rouse, 1971). The lower part of the Chuckanut Formation, of Late Cretaceous and Paleocene age, extends from Bellingham southeast into the North Cascades. See Figure 5. In contrast to the partly marine Nanaimo Group, the Chuckanut Formation is of continental origin (Miller and Misch, 1963).

In gross aspect, the Nanaimo Group is composed of alternating coarse- (sandstone and conglomerate) and fine-grained (mudstone, siltstone, and sandstone) rock units. The most recent comprehensive study of the Nanaimo Group divides it into nine formations which are segregated into four transgressive cycles (Muller and Jeletzky, 1970). Each cycle is composed of two formations - a lower coarse-grained and an upper fine-grained formation - and the group is capped by the nonmarine Gabriola Formation which records an incomplete cycle. Each depositional cycle is postulated to reflect transgression and the consequent transition in time from nonmarine to offshore marine deposition. The formations and cycles as postulated by Muller and Jeletzky are from youngest to oldest:

Deltaic - Gabriola Formation: 600 to 3000 feet of sandstone, conglomerate, and mudstone.

unconformity or disconformity

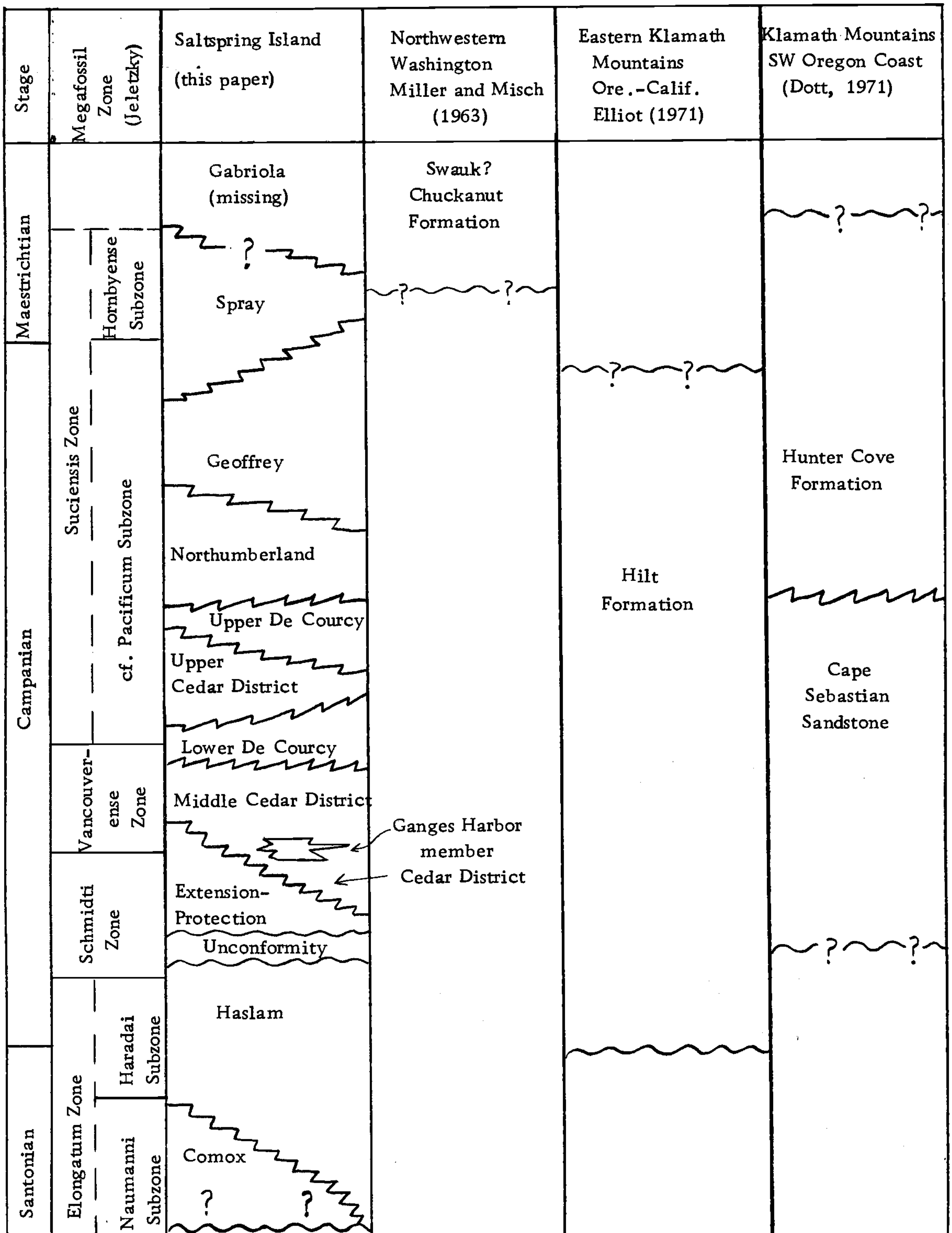


Figure 5. Correlation of Cretaceous units of thesis and other Pacific Coast sections. Contacts are gradational (jagged) or unconformable (wavy). After Muller and Jeletzky (1970).

Marine	-	Spray Formation: 950 to 1770 feet of mudstone.
Deltaic	-	Geoffrey Formation: 400 to 1500 feet of sandstone and conglomerate.
		unconformity or disconformity
Marine	-	Northumberland Formation: 500 feet of mudstone, siltstone, and sandstone.
Deltaic	-	De Courcy Formation: 900 to 1400 feet of sandstone, conglomerate and mudstone.
		unconformity or disconformity
Marine	-	Cedar District Formation: 1000 feet of mudstone, siltstone and sandstone.
Deltaic Lagoonal	-	Extension Protection Formation: 200 to 1900 feet of conglomerate, sandstone, mudstone, coal.
		unconformity or disconformity
Marine	-	Haslam Formation: 200 to 500 feet of mudstone, siltstone and sandstone.
Fluvial Lagoonal	-	Comox Formation: 150 to 2000 feet of conglomerate, sandstone, mudstone, and coal.

More recently, workers in the upper Nanaimo Group of the Gulf Islands have interpreted the succession in terms of upward-coarsening cycles of deltaic progradation (Simmons, 1973; Hudson, 1974; Sturdavant, 1975). However, they found existing stratigraphic nomenclature to be applicable and viable. This writer, too, follows the now well-established formational nomenclature of Muller and Jeletzky (1970).

Glacial Drift

Unconsolidated fluvial-glacial deposits are widespread in southwestern British Columbia. Peaks on Vancouver Island were glaciated to an elevation of 5,500 feet by the Pleistocene ice sheet (Muller and Carson, 1968). On Saltspring Island striated bedrock surfaces are common, but the bedrock is obscured in many areas (especially those underlain by nonresistant lithologies) by deposits of glacial drift.

Drift on Saltspring Island consists of stratified sand, pebbly sand and gravel. However, dark gray clay of unknown thickness does occur on the southwest shore of Ganges Harbor about a half mile southeast of Sundown Point. Much of the southwest shore of Ganges Harbor, the lowlands between Ganges and Booth Bay, and the northern slope of Mount Erskine are mantled by drift. A sand and gravel pit is operated in Lot 3 at the intersection of Booth Canal Road and Rainbow Road, 1.5 miles west of Ganges, where the deposit is more than 50 feet thick. Sand occurs in the center of Section 76 and NE. 1/4 of Section 77 on the south side of the valley of Cusheon Creek.

The area southwest of Fernwood Point, as well as the coastline for a half mile northwest of Fernwood, is covered by sand and gravel. Near the wharf at Burgoyne Bay, stratified sand dips steeply away from the south slope of Mount Maxwell. Sand occurs in the north half of Sections 79 and 86 on the northeast flank of Mount Maxwell and along much of the southwest shore of Fulford Harbor. Sand, pebbly sand, and gravel may be 100 feet thick in a pit operated 0.5 miles southwest of Fulford at the intersection of Musgrave and Isabella Point Roads. The deposits show thin trough crossbed sets, abundant cut-and-fill structures, and interlamination of coarse and fine sand.

At Cape Keppel and on the southwestern slopes of Mount Tuam is a thick accumulation of pebbly sand which is cut by ravines.

STRATIGRAPHY AND PALEOENVIRONMENTS OF THE NANAIMO GROUP

Introduction

Eight formations of the Nanaimo Group occur in the thesis area, the Comox, Haslam, Extension-Protection, Cedar District, De Courcy, Northumberland, Geoffrey, and Spray Formations. These formations, with multiple members, approximate 9,000 feet in minimum aggregate thickness and are distinguished by their combined lithology and position in sequence. Some paleontologic control is also available. The total thickness of the Nanaimo Group in the study area could be more than 12,000 feet. Table 1 is a generalized stratigraphic column of Late Cretaceous age rocks on Saltspring Island.

The lower Nanaimo Group, Comox through Extension Protection Formations, consists of three transgressive cycles of sedimentation, at least two of which were initiated by deposition of basal conglomerates on surfaces of unconformity. The upper Nanaimo Group, middle Cedar District to Spray Formations, presents a continuous record of sedimentation consisting of thick marine mudstones separated by progradational sandstone-conglomerate bodies.

Field data were compiled on aerial photographs (4 inches = 1 mile and 1 inch = 1 mile) and a topographic base map (4 inches = 1 mile). Maps and photographs were obtained from the Surveys and

Table 1. Stratigraphic section of Late Cretaceous Nanaimo group, Saltspring Island, British Columbia.

SPRAY FORMATION........ 400'? mudstone, siltstone, sandstone	
GEOFFREY FORMATION..500-800' sandstone, conglomerate, siltstone, mudstone	Upper sandstone....100-300' Conglomerate ....100-230' Lower sandstone....160-300'
NORTHUMBERLAND FORMATION .... 600-1000' mudstone, siltstone, sandstone	
INTERTONGUING NORTHUMBERLAND, DE COURCY AND CEDAR DISTRICT FORMATIONS .... more than 3000'	De Courcy 4...... 120-144' sandstone, siltstone Lower Northumberland .... 75-106' mudstone, siltstone, sandstone De Courcy 3 .... 60-260' sandstone, siltstone, mudstone, conglomerate Upper Cedar District..1450' mudstone, sandstone, siltstone De Courcy 1 ...... 200?-290' sandstone, siltstone, mudstone Middle Cedar District 1500'? mudstone, siltstone, sandstone
EXTENSION-PROTECTION FORMATION .... 180-1300'? conglomerate, sandstone, mudstone, siltstone	Upper conglomerate...0-600'? conglomerate, sandstone Middle member.....110-290' sandstone, conglomerate, siltstone, mudstone Lower conglomerate..70-240' conglomerate, sandstone
UNCONFORMITY	
HASLAM FORMATION ....600-700' mudstone, siltstone, sandstone	
COMOX FORMATION......0-1300'? sandstone, conglomerate, mudstone, siltstone carbonaceous mudstone	Upper sandstone......0-550'? sandstone, conglomerate Middle mudstone......0-150'? mudstone, siltstone, sandstone Benson conglomerate member ....0-600' conglomerate, sandstone

Mapping Branch of the British Columbia Department of Lands, Forests and Water Resources, Victoria. Observations were made with a 10X hand lens, sand gauge chart (size and roundness), Rock-Color Chart of the Geological Society of America, Brunton compass, protractor and steel tape. Section measurement was accomplished with a five-foot Jacobs staff, Abney level, and Brunton compass. Terminology for the scale of stratification is that of McKee and Weir (1953), for grain size designations the Wentworth scale, and sorting terms as given by Compton (1962). Description of the smaller-scale sedimentary structures was aided by examination of approximately 150 cut and polished slabs prepared in the laboratory. It is recommended that the reader refer to Measured Sections presented in Appendix I for detailed descriptions of stratigraphic relationships and lithologies.

Comox Formation

The Comox Formation on Saltspring Island is recognized as the basal, predominantly coarse clastic formation which underlies marine mudstone with a Santonian fauna. The name Comox Formation was introduced by Clapp (1912) for the coal-bearing sequence near Comox on Vancouver Island and was later extended to include the basal coarse clastic sequence in the Nanaimo Basin (Muller and Jeletzky, 1970). A few faunal collections from sandstones of the Comox Formation were identified for the author by J. A. Jeletzky of the Geological Survey of Canada, Ottawa. He states:

> Age and correlation. The poorly preserved, long-ranging marine pelecypod and brachiopod fauna can only be dated as of a general Upper Cretaceous age and derived from some part of the Nanaimo Group. (Jeletzky, 1973)

Areal Distribution and Thickness

The Comox Formation crops out in a belt which extends from Maxwell Creek on the west to Yeo Point on the east (Plate 1). Small outliers occur at the west end of Lake Maxwell, at Beaver Point, between Yeo Point and Beaver Point, and at Eleanor Point.

The Comox Formation is of variable thickness. On Mount Maxwell it is at least 1,300 feet thick, but is only 200 feet thick at Yeo Point, 5 miles to the east. A thickness of 297 feet was measured on the west side of Maxwell Creek (Appendix I, Measured Section C-D), but the formation is absent near the mouth of Maxwell Creek, a distance of one mile, where Haslam Formation directly overlies metamorphic basement.

Contact Relationships

The lower contact with the basement complex is a profound unconformity. It is best exposed along the west side of Maxwell Creek in lots 20, 30, and 31. The Paleozoic Sicker Group metavolcanic sequence dips about 50 degrees to the southwest and the overlying Cretaceous Comox Formation dips 20 to 30 degrees to the northwest. The surface of the contact is irregular with six feet of relief in outcrop. A basal pebble to boulder conglomerate occurs in pockets developed on the erosional surface. At Mount Maxwell Provincial Park, the Comox Formation fills a topographic low, perhaps a valley 0.75 miles wide and a few hundred feet deep. This relationship is exposed on the south face of Baynes Peak and can be observed from the summit of Bruce Peak.

The contact with the Sicker Group is also exposed at Yeo Point, on the coastline 0.6 miles south of Yeo Point, and at Beaver Point. At Yeo Point, Sicker blocks up to 20 feet diameter occur in the Comox basal conglomerate overlying green metavolcanic basement and underlying Comox Formation marine sandstone. There are 10 feet of relief over 60 feet laterally. At Beaver Point, the contact is exposed in a seacliff 100 yards west of the end of the access road. Ten feet of relief and vertical topography are present on the contact but difficult to see because of the similar color of the Sicker Group and Nanaimo Group breccia and sandstone. At all localities, except where the Comox Formation overlies Tyee Intrusion, a thin unit of green sandstone, breccia or conglomerate overlies the basement.

The nonconformable relationship between the Comox Formation and Tyee Intrusion is exposed west of Yeo Point at several localities in Sections 73 and 76, and 0.25 miles north of Eleanor Point. West of Yeo Point (NW 1/4, NW 1/4, Section 73) the contact is a very angular and blocky surface which shows 6 feet of relief over 50 feet laterally. Yellow gray to light gray cobble to boulder conglomerate is about 60 feet thick and composed of granodiorite, vein quartz and aplite clasts.

The upper contact separates shallow marine sandstone of the Comox Formation from marine siltstone and mudstone of the overlying Haslam Formation. This contact is gradational over a short interval (generally less than 10 feet) and is best exposed in the bed of Maxwell Creek in the east ends of lots 30 and 31 and on the coastline 0.25 miles southeast of the mouth of Cusheon Creek. Inland the upper contact of the Comox Formation is exposed south of Blackburn Lake along the Ganges-Fulford Highway. Along Maxwell Creek, the contact is gradational over a four-foot vertical interval. However, a sharp and planar bedding surface, which locally forms the bed of the creek, separates sandy to pebbly siltstone of the Comox Formation from overlying Inoceramus- and ammonite-bearing siltstone and mudstone of the Haslam Formation. The upper contact is also abruptly gradational near the mouth of Cusheon Creek where it occurs within an interval 20 feet thick that shows an upward-fining of grain size from pebbly sandstone to sandy siltstone (See Appendix I, Measured Section

Figure 6. Looking northwest from Captain Passage at the center of Saltspring Island. Cuestas and strike valleys on the skyline are formed by northeast-dipping Late Cretaceous rocks of the Comox Formation (Benson conglomerate, B; middle mudstone member, M; upper sandstone member, S; the latter two are repeated by faulting), Haslam Formation (H), and Extension-Protection Formation (E).

A-B). The contact records continuous sedimentation but a change in depositional environment.

Lithology and Stratification

The Comox Formation is lithologically diverse, but three informal members are recognized: the lower Benson conglomerate member, a middle mudstone member, and an upper sandstone member (Figure 7). The Benson conglomerate member attains a maximum thickness of about 600 feet on Mount Maxwell and thins to the northwest and east where it is less than 100 feet thick or absent. The middle mudstone member is a nonresistant and poorly exposed unit which underlies the topographic low extending from the north slope of Mount Maxwell to the powerlines northwest of Lake Maxwell. Thickness of the mudstone member is only approximately known. The covered interval in Measured C-D is about 100 feet thick. From constructed cross-sections, the middle member appears to be about 150 feet thick on the north slope of Mount Maxwell (south 1/2 Section 84). The upper sandstone member of the Comox Formation overlies the mudstone member and forms the prominent cuestas which extend in an arc from north of Lake Maxwell to the east end of Cusheon Lake (Plate 1 and Figure 6). Marine sandstones of this member directly overlie the Benson conglomerate or basement at Cusheon Cove, Yeo Point, Beaver Point, between Beaver Point and Yeo Point, and at

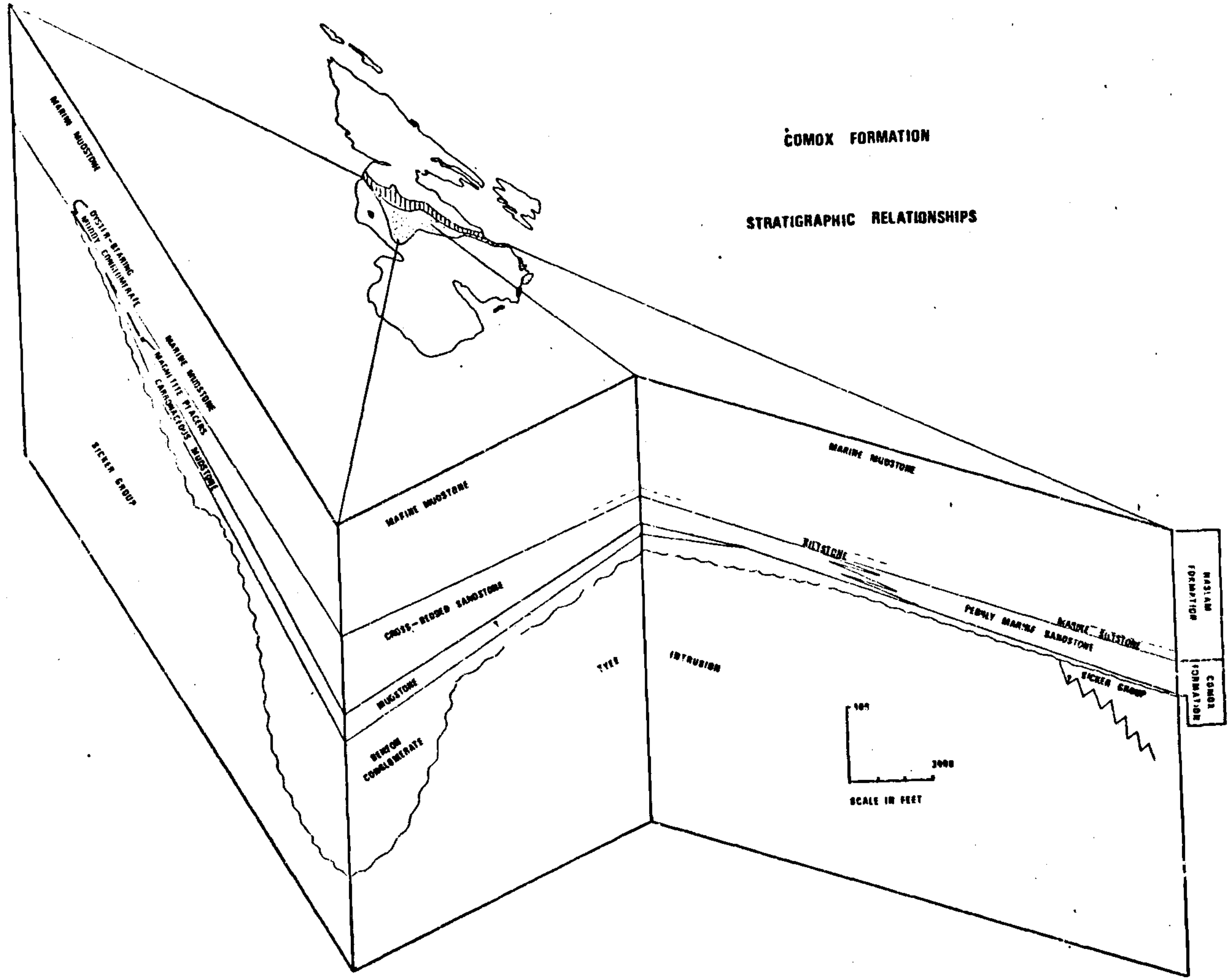


Figure 7. Comox Formation stratigraphic relationships.

Eleanor Point. The sandstone member is thickest on the north slope of Mount Maxwell where, although repeated by faulting, it is at least 400 feet thick. It thins to the northwest and east and is 146 feet thick in Measured Section C-D (Appendix I).

Benson Conglomerate Member. The Benson conglomerate is the basal conglomerate of the Comox Formation (Muller and Jeletzky, 1970) and typically is a well indurated, poorly to moderately sorted pebble to boulder conglomerate. The name was first applied to exposures on Mount Benson, west of Nanaimo (Clapp, 1912). Clasts up to two feet maximum dimension occur at Mount Maxwell Park; however, dimensions greater than one foot are uncommon. Coloration ranges from yellowish gray (5Y 7/2) and light gray (N7) to medium dark gray (N4). Clasts are mostly subangular to subrounded and consist of a diverse assemblage of lithologies including granodiorite, greenstone, diorite, schist, phyllite, vein quartz, aplite, chert, argillite, quartzite, metaquartzite, and lithic sandstones. Atypical Benson conglomerate occurs on the southwest side of Maxwell Creek (overgrown logging road in Lot 31). Poorly sorted greenish black (5GY 2/1) to light gray (N7) pebble to cobble conglomerate contains isolated greenstone boulders to 6 feet dimension. The matrix ranges from pebble conglomerate to mudstone and locally contains an abundant marine fauna of abraded Ostrea, Lima, Pecten, stout (Cidaroid) echinoid spines, and barnacle plates (balanid crustaceans).

Benson conglomerate is typically indistinctly very thick-bedded. At the west end of Mount Maxwell Park, cliff- and ledge-forming beds are 2 to 20 feet thick, broadly lenticular, and show erosional relationships. Primary structures are few and imbrication of clasts is uncommon. Interbedded thin sandstone and pebbly sandstone lenses contain thin bedding, lamination, planar cross-bedding, and ripple-drift cross-lamination (climbing ripples).

The contact with the overlying mudstone member is not exposed. At its presumed position on the north slope of Mount Maxwell, thick-bedded pebbly sandstone intervenes between the Benson conglomerate and the lowest mudstone outcrop. Therefore, the contact may be gradational.

Middle Mudstone Member. Because of a lack of outcrops, little is known about the mudstone member. In general, most of the exposures are poorly sorted, carbonaceous, and bear plant fossils. On the west side of Maxwell Park Road (east end of Lot 36, 0.3 miles northwest of Lake Maxwell) about 15 feet of brownish gray (5YR 4/1) to medium dark gray (N4) sandy carbonaceous mudstone is exposed. This poorly sorted lithology contains discontinuous thin laminations of dirty limonitic lithic sandstone to siltstone which contain abundant black coaly flakes and partings. On the north slope of Mount Maxwell, gray silty mudstone is exposed in a logging road in the SW. 1/4, Section 84.

The mudstone member of the Comox Formation contains subordinate sandstone and conglomerate. One such coarse clastic unit forms a subdued cuesta and is well exposed 0.25 miles east of Maxwell Park Road (SW. 1/4, NE. 1/4, SW. 1/4, Section 84). The cuesta-forming sequence is 15 feet thick and shows an overall upward-fining. The base consists of 3 feet of well sorted very fine pebble conglomerate which is channeled and infilled by a thin (6 inches) lens of heterogeneous material. The lens is composed of unsorted pebbles, sand, mud, intraformational micaceous mudstone clasts, coal flakes, leaf and reed impressions. Many of the mudstone clasts also contain deciduous leaf impressions. The lens is in turn truncated by light olive gray (5Y 5/2) sandstone. The sandstone is 12 feet thick, fine- to medium-grained, well sorted, with subangular to subrounded grains. It is a lithic arenite. The sandstone is laminated to thin-bedded, platy to slabby, and contains thin trough cross-bed sets (36 inches wide and 9 inches deep) and a few spherical calcareous sandstone concretions about 18 inches in diameter.

The contact of the mudstone member with the overlying sandstone member is not exposed but may locally be abrupt. At a previously mentioned locality (Lot 36), it occurs in a covered interval less than 10 feet thick.

Upper Sandstone Member. The Comox Formation sandstone member consists of a diverse assemblage of sandstones and subordinate conglomerate. It is widely distributed, extending from Maxwell Creek to Eleanor Point. The sandstone member is grossly divisible into a cliff- and cuesta-forming fluvial facies which extends from Maxwell Creek to the east end of Cusheon Lake, and a shallow marine facies which occurs east and southeast of Cusheon Lake and underlies the fluvial facies between Maxwell Creek and Cusheon Lake. The upper sandstone member is wedge-shaped and wedges out in the northwest and thins to the east (Figure 7).

Fluvial sandstones are differentiated from marine sandstones on the basis of color, textures, primary structures, and lack of marine fossils. The fluvial facies consists of well indurated, very fine- to very coarse-grained sandstone, pebbly sandstone and pebble-cobble conglomerate. Rapid lateral lithologic changes within the fluvial facies are characteristic. Sandstones are poorly to well sorted, predominantly moderately sorted, with angular to subrounded grains of quartz, feldspar, rock fragments, biotite, and magnetite. They are arkosic arenites to wackes. Colors range from pale red (10YR 6/2), moderate red (5YR 4/6) and grayish orange (10YR 7/4), weathered, and yellowish gray (5Y 7/2) to very light gray (N7), fresh.

Weathered conglomerates are light gray (N7) and consist of well sorted, subrounded to well rounded, highly spherical, pebbles to cobbles (maximum dimension 8 inches) of schist, phyllite, granodiorite, metavolcanics, vein quartz, green epidote-rich quartz, and white and pink quartzite and metaquartzite.

Stratification is well developed but of variable scale, ranging from very thick-bedded to thinly laminated. Beds are laterally discontinuous as a result of pinchout and truncation. Thin sets (2 to 24 inches) of trough and planar cross-beds and very thick cosets of festooned thin trough cross-beds are common. Also prevalent are broad shallow channels (up to 3 feet deep and a few tens of feet wide), conglomerate lenses and bands, and interlaminated coarse and fine sandstone.

Conglomerate occurs primarily north of Lake Maxwell where it exists as beds and lenses up to 5 feet thick. Many of the lenticular bodies infill channels which cut the enclosing laminated sandstones and pebbly sandstones. Conglomerate of the sandstone member, unlike the Benson conglomerate, is commonly well sorted and highly rounded.

Limited organic remains in the fluvial sandstones consist of wood fragments and impressions of fragmented leaves.

Marine sandstones of the Comox Formation upper sandstone member are well exposed at Yeo Point, Beaver Point, north of Eleanor Point, and in the seacliffs west of Cusheon Cove. Abraded mollusk shells occur at all of these localities. In addition, marine sandstone occurs near the base of the upper sandstone member 0.5 miles north of Lake Maxwell and probable marine sandstone directly overlies the middle mudstone member 0.35 miles northeast of Lake Maxwell.

At Beaver Point fossiliferous greenish sandstone, pebbly sandstone, and conglomerate occur. Coloration is pale olive (10Y 6/2) fresh, and olive gray (5Y 3/2) weathered. The sandstones show a wide range of size and sorting but generally lack intergranular matrix and consist of angular to subrounded rock fragments, quartz, chert, and epidote. The sandstone is laminated to thick-bedded, and most beds are visibly lenticular. Some outcrops consist of a complex of cross-cutting, broad, shallow channels which range from 2 to 30 inches deep and a maximum of several tens of feet wide. Channels are recognized by their geometry and the cut-and-fill relationship to surrounding rocks. Commonly coarse-grained sandstone channels cut fine-grained laminated sandstones, or pebbly sandstone and conglomerate channels cut sandstones and pebbly sandstones. Many channels contain in the axis a lag concentrate of pebble conglomerate and abraded pelecypod valves. Trough cross-beds and wave ripple marks are rare; the ripples have symmetrical and asymmetrical profiles and parallel linear crests.

West of Cusheon Cove, well sorted, fine- to very fine-grained sandstone is locally laminated, channeled, and contains pelecypod valve fragments and rare vertical tubular burrows. Marine sandstone also crops out in the west end of section 76 at Peter Arnell Park where bioturbated very poorly sorted sandstone contains abraded pelecypod valves. Burrows consist of arcuate irregularly meandering tubes about 0.5 inches diameter which have an argillaceous lining and follow or cross bedding planes at low angles. The burrows are identified as Planolites (Figure 8) (Chamberlain, written communication, 1975).

At Eleanor Point, fossiliferous very fine-grained pebbly silty sandstone contains abundant marine fossils and carbonaceous material. This distinctive unit is 30 feet thick, pyritic and rusty-weathering, laminated to thinly laminated (where not bioturbated), and contains sparse matrix-supported well rounded pebbles of green dacite porphyry and white quartz. Notable characteristics are the intensity of bioturbation, moldic porosity after fragmented pelecypod and brachiopod valves, abundant small coaly flakes, and calcareous sandstone concretions up to 2.5 feet diameter. The sequence also contains thin lenses of siltstone which are a maximum of 3 inches thick and 4 feet wide.

Organic remains include permineralized (pyrite and calcite) wood with Teredo borings, a Nautiloid cephalopod, the brachiopod "Rhynchonella," and pelecypods Trigonia, Ostrea, and Modiolus (mollusk and brachiopod identification by Jeletzky (1973)). Many small subspherical calcareous concretions about 2 to 3 inches in diameter contain a nucleus of mollusk hash and/or small tubular burrows. Trace fossils are abundant and consist of meandering tubes of Planolites, Asterosoma-Teichichnus type bioturbation, and

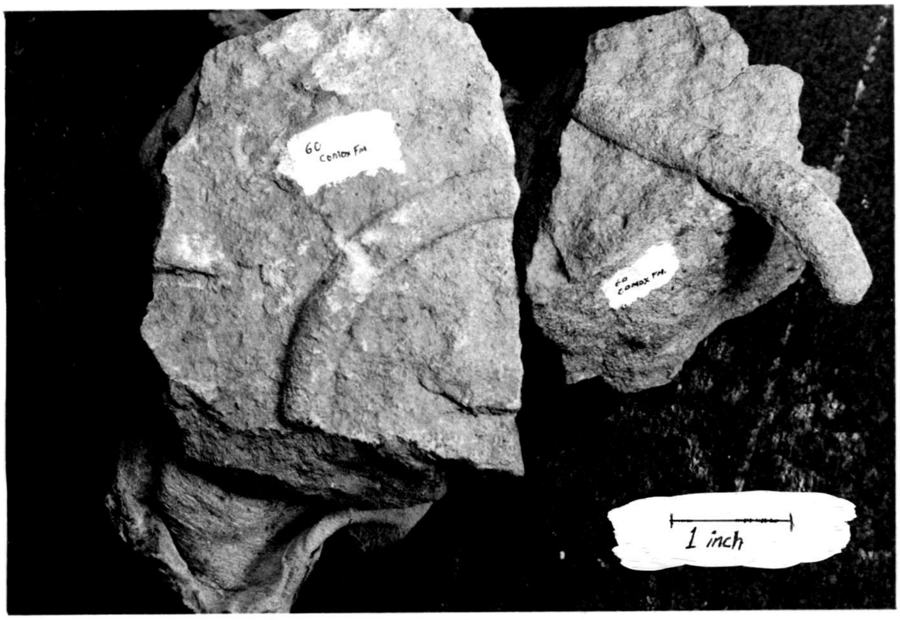


Figure 8. Trace fossil, Planolites, from the Comox Formation shallow marine sandstones at Peter Arnell Park. The plane of the photograph is approximately parallel to bedding.

Helminthoida or Phycosiphon (Chamberlain, written communication, 1975). Planolites is elliptical in cross-section and contains a light gray infill which lacks the intergranular argillaceous matrix present in the enclosing sandstone. Asterosoma-Teichichnus type bioturbation consists of subhorizontal dark argillaceous lenses less than 1 by 10 millimeters.

An unusual black heavy mineral sandstone crops out on the cuesta scarp 0.5 miles north of Lake Maxwell (W. 1/2, W. 1/2, Lot 13). Coloration is metallic medium dark gray (N4) fresh and brownish black (5YR 2/1) to dark reddish brown (10R 3/4) weathered. It consists of very fine- to fine-grained, very well sorted, angular to subrounded grains of magnetite (up to 70 percent opaques), other heavy minerals, and calcite cement. The bed varies from thinly laminated to structureless and at one locality is a minimum of 10 feet thick (base covered). The bed is lenticular and replaced within a few hundred yards to the southeast by very fine grained, rusty weathering sandstone with heavy mineral laminae which is in turn replaced laterally by a sequence of sandstone and conglomerate. The top of the heavy mineral sandstone is exposed 1,800 feet to the northwest in the east end of Lot 33 where it is overlain by festooned thinly cross-bedded sandstone. The heavy mineral sandstone grades upward through a two-foot interval into 5 feet of laminated to thin-bedded and thinly cross-bedded, fine- to medium-grained, moderately to well sorted sandstone with heavy mineral laminae. The sandstone is medium light gray (N6) weathered, and yellowish gray (5Y 7/2) fresh. The gradational upper contact is marked by isolated well rounded cobbles.

Probable marine sandstone overlying the middle mudstone member northeast of Lake Maxwell is pale yellowish brown (10YR 6/2) to yellowish gray (5Y 7/2), very fine- to medium-grained, well sorted, laminated to thick-bedded with a massive to slabby parting. The sandstone is locally thinly cross-bedded and contains a few ellipsoidal calcareous sandstone concretions which are oriented with their long axes (up to 2.5 feet) parallel to bedding. The sequence is overlain by coarser, cavernous-weathering, channeled fluvial sandstones and pebbly sandstones.

Depositional Environments

The Comox Formation accumulated in a variety of continental and nearshore marine environments. Paleocurrents (Figure 58) and facies changes (Figure 7) suggest that a lobate area of nonmarine deposition was flanked from northwest, through east to southeast by nearshore marine deposition in beaches, bars (?), small tidal channels and local embayments (Figure 63).

Fossiliferous breccia and basal conglomerate at Yeo Point, Beaver Point, and between Yeo Point and Beaver Point were deposited at the base of seacliffs during shoreline retreat and initial transgression of the Late Cretaceous seaway. Lack of rounding and sorting, the occurrence of boulders, and the similarity of clast and basement lithologies all indicate that the sediment was rapidly deposited and locally derived. Overlying marine sandstones and conglomerates accumulated as shallow marine deposits along a coastline of appreciable relief. Deposition was possibly in littoral environments such as sand and gravel beaches and tidal creeks. The fauna of oysters and other thick shelled pelecypods (including those of Mytilid affinities - Modiolus) suggests high energy brackish and normal marine environments, presumably littoral to inner neritic (Table 2). Large wood fragments and leaf fragments in the well sorted sandstones also support nearshore deposition. Probable beach or shoreface environments are recognized as intensely winnowed and sorted sandstone with multiple scour-and-fill, linear-crested ripples (wave ripples), lamination, and abraded thick-shelled pelecypods. Possible tidal or subtidal creek channels are recognized by their lenticular geometry, cross-cutting relationship with beach sandstone, and the axial lag concentrates with reworked pelecypod valves. Burrows similar to the Planolites of Peter Arnell Park are known to occur in shallow marine, probably lower shoreface deposits, and could have been made by shrimp in a firm substrate (Chamberlain, personal communication, 1975). The basal "muddy" conglomerates of Maxwell Creek are inferred to have been deposited as a lag concentrate during marine transgression. Subsequent to initial inundation, lower energy conditions prevailed during silt and mud deposition. The fauna of oysters, barnacles, and stout urchins indicates a littoral environment. Sediments of comparable texture and a similar biota accumulate today as the intertidal deposits of bays and inlets of the Gulf Islands, and a similar paleodepositional environment is postulated for the Comox Formation muddy conglomerate.

Intensely bioturbated, pyritic and argillaceous sandstones and siltstones at Eleanor Point were deposited in a fairly low energy but probably intertidal marine environment such as a bay. The rather good sorting (moderate to well) but lack of winnowing suggests a lack of extended exposure to vigorous waves or currents. Intense bioturbation occurred during slow deposition when organisms were able to thoroughly churn the substrate. The brachiopod "Rhychonella" (Jeletzky, written communication, 1973), common at Eleanor Point, is indicative of a quiet shallow water environment (Boucot, 1975). The trace fossil assemblage Planolites, Asterosoma-Teichichnus type bioturbation, and Helminthoida or Phycosiphon is compatible with shallow marine deposition (Chamberlain, written communication, 1975). Teichichnus is known from offshore to lower shoreface facies. Asterosoma occurs in the offshore-shoreface transition, and Asterosoma and Teichichnus occur together in lower shoreface deposits of the Cretaceous of east-central Utah (Howard, 1972).

Rich concentrations of heavy minerals at the base of the upper sandstone member were deposited as beach placers. The heavy mineral sandstones occupy a position between "muddy" conglomerate and the Haslam Formation marine mudstone to the northwest, and the main body of the fluvial sandstones to the southeast (Figure 7). Rich placers are characteristic of shorelines and form on the upper foreshore of the Oregon coast (black sand "winter beaches") and Nile Delta (Soliman, 1964), open beaches of the Gulf Coast (Stapor, 1973), and elsewhere in storm-built beach ridges (berms) at the backshore. Concentration depends upon availability of heavy minerals and a special wave regime (storm waves) in which strong incident waves move sediment onshore and preferentially deposit heavy minerals because the backwash is capable of sweeping only the light mineral grains back into the surf zone.

The main body of the Benson conglomerate member was deposited in a valley by high energy streams which drained a nearby source of high relief. Grain size and thickness of the conglomerate body decrease to the northwest and east away from Mount Maxwell. Rapid fluvial deposition is indicated by the coarse grain size, commonly poor sorting, angularity of clasts (locally breccias), generally poor stratification, and large-scale channels. Fluvial processes are also suggested by the interbedded sandstone lenses which contain interlamination of coarse and fine grain sizes, ripple-drift cross-lamination (climbing ripples), planar cross-bedding, and matrix-supported pebbles.

Very different environments are recorded by the overlying Comox Formation mudstone member. Significant features of the mudstone member include the overall poor sorting and fine grain size (micaceous sandy mudstone), and the abundance of plant fossils, coal laminae and flakes. Discontinuous thin laminae consist of limonitic sandstone, siltstone, mudstone and coal. These features, especially the textural immaturity, fine grain size and abundance of fossil plant remains, suggest deposition in a coastal swamp, protected tidal flat, or floodplain where terrestrial plants are plentiful and sediments settle from suspension and are not reworked. Sandstone bodies in the mudstone member may have been deposited in fluvial or tidal channels. Multiple scour-and-fill, lamination, trough cross-bedding, plant fossils, and heterogeneous debris flow deposits suggest fluvial deposition. Trough cross-bedding records scour and infill by migrating crescentic dune bed forms and records tractive transport to the northwest. The vertical grain size sequence (upward-fining from pebble conglomerate to fine-grained sandstone) and association of the sandstone bodies with a dominantly argillaceous interval, suggests a relatively low-gradient and possibly meandering channel system (Selley, 1970).

The fluvial facies of the Comox Formation upper sandstone member was deposited by higher velocity traction currents. Fluvial features are widespread and include highly lenticular bedding and rapid lateral facies changes, planar and trough cross-bedding, interlamination of coarse and fine sandstones, and abundant channeling. Except for plant fragments, organic remains and traces are absent. Festooned cross-bedding and the lenticular geometry of sandstone bodies is a result of sedimentation by alternate scour and fill. The virtual lack of fine-grained overbank mud and silt and abundance of channeling are characteristic of low sinuosity braided streams which, because of their high gradients and sediment load, are subject to repeated channel switching to form a network of braided channels (Selley, 1970). Primary structures record sediment transport to the north (Figure 58). The apparent character of fluvial processes, rapid down-current wedging of the fluvial sandstone body and lateral gradation into shallow marine deposits (Figure 7), and lobate area of deposition suggest a delta or fan delta depositional system (Fisher and Brown, 1972). See Comox-Haslam Depositional System.

Haslam Formation

On Saltspring Island the Haslam Formation is a thick mudstone sequence which overlies the Comox Formation or rests directly upon metamorphic basement. The Haslam Formation contains the oldest diagnostic marine macrofauna known from the Nanaimo Group. The name Haslam Formation, after Haslam Creek near Nanaimo, was introduced by Clapp (1912) for a thick mudstone body which underlies the coal bearing strata at Nanaimo. After paleontologic confirmation, the Haslam Formation was later extended to include the lower Trent River Formation of the Comox Basin, 65 miles north of Nanaimo (Muller and Jeletzky, 1970).

Faunal collections from five localities were identified for this writer by the Geological Survey of Canada (Jeletzky, 1973). The predominantly Inoceramus and ornamented ammonite faunas belong to the late Santonian to early Campanian Bostrychoceras elongatum biozone as defined by Jeletzky (Muller and Jeletzky, 1970) and include probable representatives of both the Santonian Inoceramus naumanni subzone and Campanian Pachydiscus Eupachydiscus? haradai subzone of the B. elongatum zone (Figure 5). However, according to Jeletzky, subzonal assignments can not be made with certainty because of the limited number of specimens or/and their poor preservation.

Areal Distribution and Thickness

The Haslam Formation underlies a narrow strike valley which extends for 7.5 miles across the middle of Saltspring Island from the mouth of Maxwell Creek to the mouth of Cusheon Creek (Plate 1).

The northwest- to west-trending valley is 0.2 to 0.7 miles wide and occupied by several lakes. Haslam Formation is also exposed near Fulford, 0.5 to 1.3 miles northwest of Isabella Point, and is inferred to underlie the entire southwest shore of Fulford Harbor. Probable Haslam Formation underlies the southernmost tip of the study area at Cape Keppel in a narrow belt about 1.5 miles long and less than 0.25 miles wide.

In the middle of the island, although the width of the strike valley varies as a result of topography and cross-faulting, the Haslam Formation is of near uniform thickness. At the mouth of Cusheon Creek, a thickness of 670 feet was measured (Measured Section A-B) and a thickness of 600 feet was measured in the canyon of Maxwell Creek (Measured Section D' E). Thicknesses at Fulford Harbor and Cape Keppel are not known. Measurement is precluded by (mass-wasting) and (lack of exposure). At Cape Keppel, the section is also complicated by disharmonic folding, but is probably a few hundred feet thick.

Contact Relationships

Lower Contact. The lower contact with the Comox Formation has been described previously. It is apparently conformable and lithologically gradational, and separates sandstones and conglomerates of the Comox Formation from marine siltstones and mudstones of the Haslam Formation.

At the mouth of Maxwell Creek, Haslam Formation mudstone overlies Sicker Group metavolcanics. The contact, an angular unconformity, is well exposed in the bed of Maxwell Creek and along the new access road to the public beach (intertidal delta) at the mouth of Maxwell Creek. The contact surface is irregular with local relief of up to six feet infilled by pockets of pebble to boulder conglomerate. The conglomerate is composed of well rounded, grain-supported clasts of schist, phyllite, greenstone and quartz with a dark gray (N3) mudstone matrix. Faintly stratified platy mudstone overlies both the basement and pockets of conglomerate. The contact surface dips more steeply to the northeast (N. 66° W., 57° E.) than does the overlying Haslam Formation (N. 56° W., 28-40° E.). Therefore, it seems probable that deposition occurred on a surface which was inclined at least 17° to the northeast.

On the southwest shore of Fulford Harbor, Haslam Formation mudstone (0.5 miles northwest of Isabella Point) is either in fault contact with or directly overlies the basement. However, the exact position of the contact is not exposed. At Cape Keppel, the lower contact is inferred to lie offshore in Satellite Channel.

Upper Contact. The upper contact with the Extension-Protection Formation, although rarely exposed, is of variable character. At the mouth of Cusheon Creek, the contact is sharp and disconformable with up to six inches of erosional relief observable in outcrop. Small pebbly sandstone channels cut silty mudstone of the Haslam Formation. The channels contain rare mudstone and micritic mudstone clasts which are identical to lithologies of the subjacent Haslam Formation. The channels are overlain by the basal conglomerate of the Extension-Protection Formation. If angular discordance exists, it is slight, two degrees or less.

On the west coast of Saltspring Island, 0.3 miles northeast of the mouth of Maxwell Creek, Haslam Formation mudstone is in fault contact with a vertically sheared conglomerate sequence of the upper Extension Protection Formation.

East of Cape Keppel (SW. 1/4 Section 32), a sequence of dark gray mudstone, provisionally correlated with the Haslam Formation, is conformably overlain by sandstone and conglomerate. (Although paleontologic confirmation as to the identity of the mudstone sequence is lacking, it is lithologically similar to the Haslam Formation. Also, lithologic and petrographic data favor correlation of the overlying sandstone and conglomerate with the lower Extension-Protection Formation. (See Appendix II, Modal Analyses of Sandstones.)

The contact is intercalated and gradational. The stratigraphically highest mudstone-dominated unit (100 feet thick) is replaced upward over an interval of 20 feet by sandstone with minor mudstone. The contact, which is characterized by an overall upward coarsening of grain size, thickening of sandstone interbeds and concomitant thinning and eventual absence of dark gray mudstone beds, records continuous sedimentation but a change in depositional environment.

Lithology and Stratification

The Haslam Formation is lithologically uniform. It is typically a nonresistant but well-indurated, massive to slightly platy mudstone which forms valleys, subdued seacliffs and broad intertidal shore platforms. Fresh material is tenacious and durable but weathers into tiny chips within a few months. Exposures in gulleys and shallow excavations exhibit spheroidal weathering with manganese and iron oxide stain between exfoliation sheets. Calcareous mudstone concretions are common and weather out in relief. Minor amounts of siltstone and interbedded sandstone also occur.

Most of the Haslam Formation consists of fossiliferous and concretionary mudstone. The mudstone contains variable proportions of silt and clay, ranges from siltstone to silty claystone, and is generally finest in the main body of the formation at least several tens of feet away from the lower and upper contacts. Coloration is medium dark gray (N4) to dark gray (N3), fresh and weathered. Weathered micritic mudstone concretions are light gray (N7) and vary from spheres and ellipsoids which attain 3 feet in diameter to lenses as much as 3 feet thick and 20 feet long. Some of the smaller concretions are septarian. Pyrite, ammonite and Inoceramus fossils, carbonized wood fragments, minute burrows, and comminuted mollusk shells occur within the smaller concretions. Weathered color of pyritic concretions is moderate yellowish brown (10YR 5/4) to dark yellowish orange (10YR 6/6). Pyrite occurs as minute, disseminated cubes, aggregations up to 0.5 inches diameter, and within the chambers of ammonite fossils.

The basal Haslam Formation near the mouth of Cusheon Creek consists of sandy siltstone to clayey siltstone. Present are spherical calcareous siltstone concretions one to two inches in diameter. Crustacean remains, including pincers, were found in a few of the concretions. Trace fossils resembling Thalassinoides occur on siltstone bedding planes as arcuate to branching horizontal tubes which are elliptical in cross-section and 0.5 inches in maximum diameter. Along Maxwell Creek, the basal Haslam Formation consists of thinly laminated siltstone which is overlain by a sequence of mudstone and thin siltstone interbeds. The latter are 3 to 9 inches thick and laterally continuous in outcrop. Intervening mudstones contain small ellipsoidal calcareous mudstone concretions with rare ammonite and Inoceramus remains.

At the mouth of Cusheon Creek, the upper Haslam Formation contains lenticular siltstones which are 0.2 to 1 inches thick, pinch out within a few tens of feet laterally and are indistinctly cross-laminated. Laminations and lenses of carbonized vegetal debris occur in this unit near the mouth of Maxwell Creek.

The sequence at Cape Keppel contains rhythmic interbeds of very fine- to fine grained sandstone. The sandstones range from 0.25 to 16 inches thick and are separated by mudstone intervals 1 inch to 20 feet thick. The interbeds are laterally persistent, have sharp and planar lower contacts and predominantly gradational upper contacts. Internal structures consist of thin planar laminations, contorted laminations, and normal grading. Rare Thalassinoides-like burrows occur on the tops of the sandstones.

Depositional Environment

The Haslam Formation accumulated in a low-energy marine setting which was at least periodically suitable for marine life and locally subject to weak current action. The mega- and microfauna suggest a neritic environment and open communication with the Pacific Ocean (Muller and Jeletzky, 1967; Scott, 1974) (Table 2). Foraminifera from the Haslam Formation near Comox suggest "outer shelf to

Table 2. Probable habitat of Pelecypoda and Gastropoda from Comox, Haslam, and Extension Protection Formations.

Fossil	Formation	Habitat of Modern Genus
Lima	Comox *Haslam	Intertidal to 4,000 feet, free-swimming or in transparent nests
Nucula	Comox *Haslam	30 to 6,000 feet
Modiolus	Comox	Intertidal to 230 feet, attached to rocks or in sand
Ostrea	Comox	Intertidal to 110 feet, cemented to hard substrates
Pecten	Comox	15 to 560 feet, free-swimming
Trigonia	Comox	**Extinct, presumably littoral to inner neritic
Anomia	*Haslam	Intertidal to 140 feet, attached to rocks or other shells
Cyclichna	*Haslam	15 to 600 feet
Inoceramus	Haslam	**Extinct, presumably shelf to at least upper bathyal
Thracia	*Haslam	Intertidal to 440 feet
Yoldia	Haslam	Intertidal to 6,000 feet
Glycimerus	Extension-Protection	Intertidal to 1,100 feet

upper depths" of about 200 meters (Sliter, 1973).

The texture and lateral uniformity of Haslam Formation lithology suggests uniform conditions throughout the study area and deposition primarily by settling from suspension of silt and clay. Sediments resemble those of an open shelf, away from fluvial or deltaic influence (Allen, 1970). Weak bottom currents deposited the siltstone and sandstone interbeds and lenticular laminae.

The trace fossil *Thalassinoides* is formed by deposit feeders, probably crustaceans, which inhabit areas of slow deposition and quiet water. *Thalassinoides* is known from the Cretaceous to Holocene, is commonly reported from turbidite sequences, and is inferred to imply outer shelf to upper bathyl water depths (Howard, 1966; Fern and Warme, 1974).

Chemically reducing and high pH (alkaline) conditions occurred in the Haslam sediment. Carbonate-cemented concretions may have resulted from post-depositional alkaline conditions around decaying organic matter. Creation of a local alkaline environment by evolution of ammonia around decomposing proteinaceous organic matter results in precipitation of calcium carbonate from interstitial water and formation of mudstone concretions (Weeks, 1953):

$$NH_3 + Ca^{++} + HCO_3^- \rightarrow CaCO_3\downarrow + NH_4^+ \ .$$

Besides raising the pH, ammonia reacts with bacterially generated CO_2 to form dissolved carbonate and bicarbonate ions (Berner, 1968):

$$CO_2 + NH_3 + H_2O \rightarrow NH_4^+ + HCO_3^-; \; CO_2 + 2NH_3 + H_2O \rightarrow 2NH_4^+ + CO_3^= .$$

The pyrite bearing concretions and abundant organic material suggest post-depositional reducing conditions. Iron sulfide could have been formed by sulfate-reducing bacteria (anerobic conditions) or by the reduction of sulfate by naturally generated methane (Prokopovich, 1973).

Comox-Haslam Depositional System

The Comox and Haslam Formations record continuous sedimentation which is characterized by an overall upward-fining of grain size. The vertical sequence in which nonmarine and nearshore marine deposition is supplanted by quiet-water offshore marine deposition conforms to the first transgressive cycle of sedimentation proposed by Muller and Jeletzky (1970). The vertical succession of facies reflects transgressive onlap and landward migration of the shoreline and depositional environments (Visher, 1965).

The Comox upper sandstone member may record a minor regressive phase superimposed upon the overall Comox to Haslam transgression. North of Lake Maxwell the sequence of depositional environments is: fluvial (Benson conglomerate); coastal swamp, floodplain, tidal flat or bay (middle mudstone member); littoral including beach (heavy mineral sandstone and well-sorted concretionary sandstone of basal upper sandstone member); braided fluvial (cross-bedded, channeled, coarse sandstone and conglomerate of upper sandstone member); nearshore to offshore marine (Haslam). The Comox upper sandstone member may have been deposited as a delta or fan delta (Fisher and Brown, 1972) which prograded across quiet water deposits of the middle mudstone member. See Discussion of Depositional System.

Extension-Protection Formation

The Extension-Protection Formation is the coarse clastic sequence which overlies the Haslam Formation. Equivalent strata were extensively studied and subdivided in the Nanaimo coal fields (Clapp, 1912) but were later grouped into a single formation (Muller and Jeletzky, 1970). The formation was named after its most prominent members: the Extension conglomerate (after the town of Extension) and the Protection sandstone (after Protection Island in Nanaimo Harbor). Several informal subdivisions are recognized on Saltspring Island.

No diagnostic zone fossils were found in the Extension-Protection Formation. A single faunal collection contained pelecypods of a "general Upper Cretaceous age" (Jeletzky, 1973).

Areal Distribution and Thickness

The Extension Protection Formation underlies three narrow northwest-trending belts (Plate 1). It occurs primarily as a prominent cuesta- and hogback-former which forms Mount Erskine and Mount Belcher and extends across the middle of the study area from the mouth of Maxwell Creek to the mouth of Cusheon Creek. A sandstone and conglomerate body developed in the overlying Cedar District Formation is here referred to as the Ganges Harbor member of the Extension Protection Formation. The member occurs along the outer southwest shore of Ganges Harbor and extends inland to Beddis Road. A thin sequence of probable Extension-Protection Formation occurs at Cape Keppel.

The Extension Protection Formation is of variable thickness. In the Nanaimo area it is estimated to attain 1900 feet (Muller and Jeletzky, 1970). In the main outcrop belt on Saltspring Island, it ranges from more than 1,000 feet thick on Mount Erskine to only 180 feet thick at the mouth of Cusheon Creek (Appendix I, Measured Sections A-B, D'-E). An incomplete section of 970 feet was measured on Mount Erskine where the total thickness is estimated to be 1,300 feet. The Ganges Harbor member is severely faulted and sheared but should be at least 500 feet thick. The sequence at Cape Keppel is incomplete but a thickness of about 200 feet occurs between the Haslam Formation and a fault contact with the Sicker Group.

Contact Relationships

As discussed previously, the lower contact with the Haslam Formation is locally unconformable. The upper contact with the lower and middle Cedar District Formation is invariably gradational; it is best exposed immediately north of the mouth of Cusheon Creek (Measured Section A-B) where approximately 90 feet of sandstone and siltstone intervene between the basal conglomerate of the Extension-Protection Formation and the mudstone of the overlying lower Cedar District Formation. The upper contact is also exposed on the southeast shore of Booth Bay about 0.5 miles north of the mouth of Maxwell Creek. An abrupt gradation from conglomerate to mudstone occurs over a stratigraphic interval of less than 100 feet.

Lithology and Stratification

In the study area the Extension-Protection Formation is divided into 4 members: the lower conglomerate member, dominated by conglomerate and sandstone; the middle member which consists of sandstone, conglomerate, siltstone, and mudstone; the upper conglomerate member of conglomerate and sandstone; and the Ganges Harbor member which lies about 1,000 feet stratigraphically above the other three and is formed of sandstone, conglomerate and mudstone (Figure 10).

Lower Conglomerate Member. The lower conglomerate member is a cliff-forming unit which is exposed on the antidip slope of the main outcrop belt of the Extension-Protection Formation. It is a basal conglomerate; it lies upon an unconformity and constitutes the base of a sequence. The lower conglomerate member is 93 feet thick at the headland on the north side of the mouth of Cusheon Creek (Plate 1). A thickness of 241 feet was measured at the east end of Mount Erskine.

Weathered color varies from moderate brown (5YR 4/4) to dark yellowish brown (10YR 4/2) and olive gray (5Y 4/1). The lower conglomerate member is composed of laterally extensive pebble to cobble conglomerates which are indistinctly very thick-bedded and not confined to discrete channels. Conglomerates are well indurated and composed predominantly of subangular to rounded medium to coarse pebbles of gray chert, quartz, and argillite. The matrix is medium- to coarse-grained sandstone rich in quartz, feldspar and dark rock fragments.

Sandstone is a subordinate part of the lower conglomerate member and occurs as medium light gray (N6) to light gray (N7), fresh and weathered, discontinuous beds and discrete channels up to 10 feet wide and 1.5 feet deep. The sandstone is medium- to very coarse-grained, moderately sorted, and locally pebbly, calcareous and laminated.

Middle Member. The middle member of the Extension-Protection Formation forms a distinctive interval of subdued cliffs and slopes between the lower and upper conglomerate members. On Mount Erskine it is 287 feet thick (Figure 9). The contact with the lower conglomerate member is both conformable and gradational.

The middle member is a lithologically diverse sequence of sandstone, conglomerate and lesser siltstone and mudstone. Stratification is conspicuous and of variable scale ranging from very thick-bedded to laminated. Beds are laterally discontinuous as a result of truncation and pinch out. Coastal exposures of sandstone are olive gray (5Y 5/1), weathered. Inland, weathered color is various shades of gray, brown, yellow brown, and red. Fresh color is medium light gray (N6). Sandstones range from very fine- to very coarse-grained and pebbly, are poorly to well sorted, and consist of angular to subangular grains of quartz, feldspar, rock fragments and mica. Intergranular matrix is often abundant.

The lower part of the middle member is conglomeratic. Many of the pebble to cobble conglomerate bodies are highly lenticular channels which show cut-and-fill relationships with adjacent beds. At one locality a discontinuous bed of pale brown (5YR 5/2) laminated mudstone drapes and fills channel topography developed on

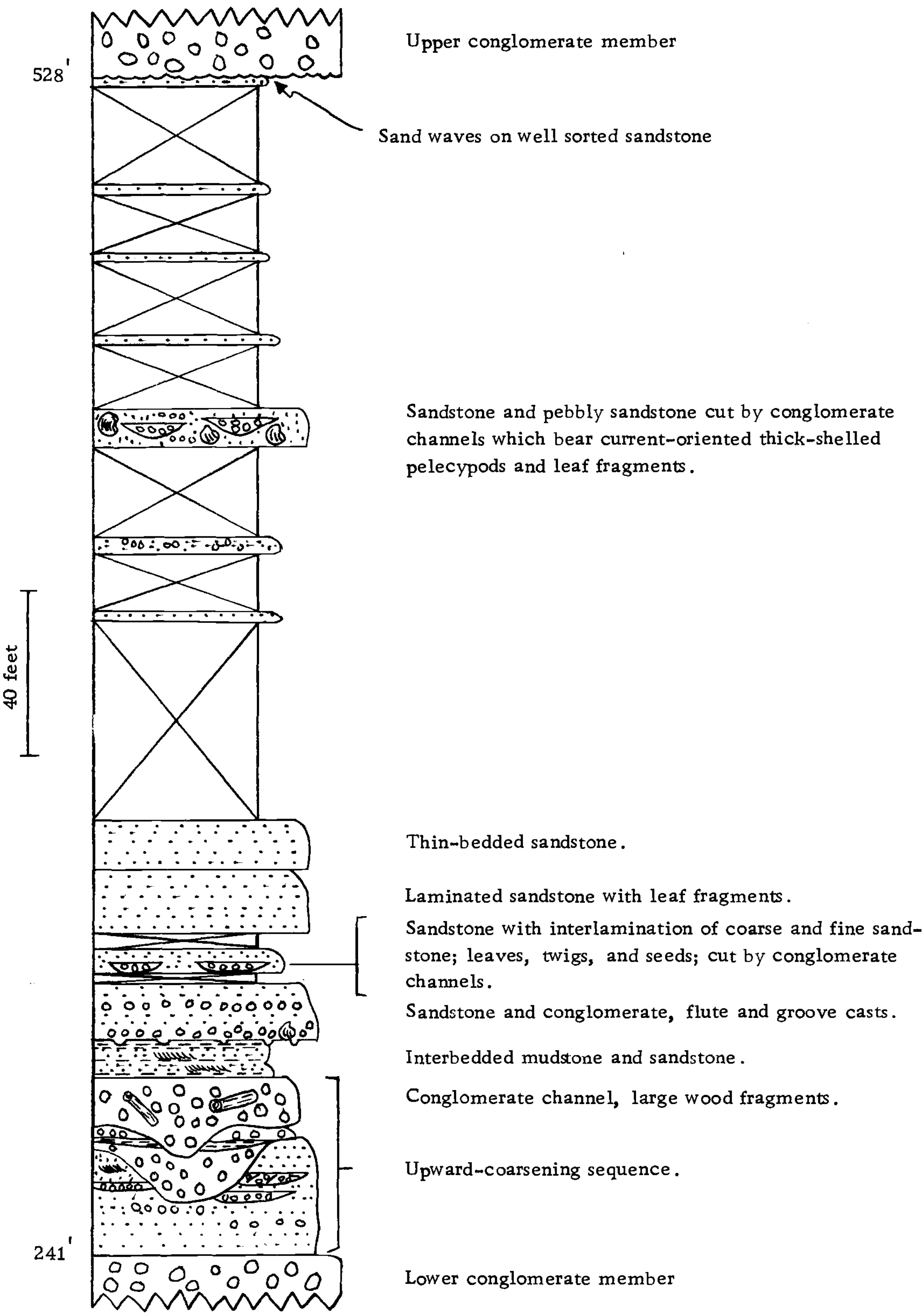


Figure 9. Stratigraphic section of middle member of Extension-Protection Formation on Mount Erskine (Measured Section D'-E).

conglomerate. The mudstone is cut by a larger conglomerate channel which bears large wood fragments and shows 6 feet of erosional relief over 50 feet laterally (Figure 9).

Several types of sedimentary structures occur in the middle member. Trough and planar cross-beds are common to sandstones and pebbly sandstones, with sets up to 3 feet thick. Interlamination of coarse and fine sandstones is widespread, and interlamination of sandstone with mudstone, and siltstone with carbonaceous mudstone occurs. Lamination also results from concentrations of flat-lying mica and carbonaceous plant debris. Channeling is common. Other structures include cross-lamination, parting lineation, sand waves, pebble imbrication, rare normal grading in sandstone and conglomerate, and flute and groove casts.

There is a close spatial association of terrestrial flora and littoral fauna. Fragments of fossil wood and foliage are common. One laminated sandstone bears abundant fossilized deciduous leaves, twigs and seeds. A stratum consisting of pebbly sandstone with cross-cutting conglomerate channels contains an abundance of current-oriented and broken thick-shelled pelecypods (including Glycimerus) and fragmentary plant material (at 428 feet, Measured Section D'-E, Appendix I).

Upper Conglomerate Member. The upper conglomerate member of the Extension-Protection Formation conformably overlies the middle member. The contact is invariably sharp and planar and well exposed along the southwest face of Mount Erskine where conglomerate rests upon well sorted sandstone. Locally the conglomerate rests upon sand waves (wavelength 18 inches, amplitude 2 inches). Above Old Divide Road (0.75 miles north-northwest of Cusheon Lake), the upper conglomerate rests upon mudstone and bears angular mudstone clasts (up to six inches dimension). Although definitely erosional, the contact is planar and believed to represent only minor erosion of essentially contemporaneous mud deposits.

The upper conglomerate member is a markedly wedge-shaped unit which has a maximum thickness in the northwest, thins to the southwest, and finally wedges out near Cusheon Lake in the southwest 1/4 of Section 87. A thickness of 440 feet was measured at the east end of Mount Erskine between the middle member and a major northwest-trending fault. The maximum total thickness is estimated to be at least 600 feet. Above Old Divide Road, the upper conglomerate member is less than 100 feet thick and only 30 feet of conglomerate is present (the remainder being sandstone).

The upper conglomerate member forms imposing cliffs on the southwest faces of Mount Erskine and Mount Belcher. Coloration is pale yellowish brown (10YR 6/2), in overall weathered aspect. It is indistinctly very thick-bedded (4 to 60 feet) and composed of fine pebbles to boulders 6 feet across. Coarse pebbles and cobbles

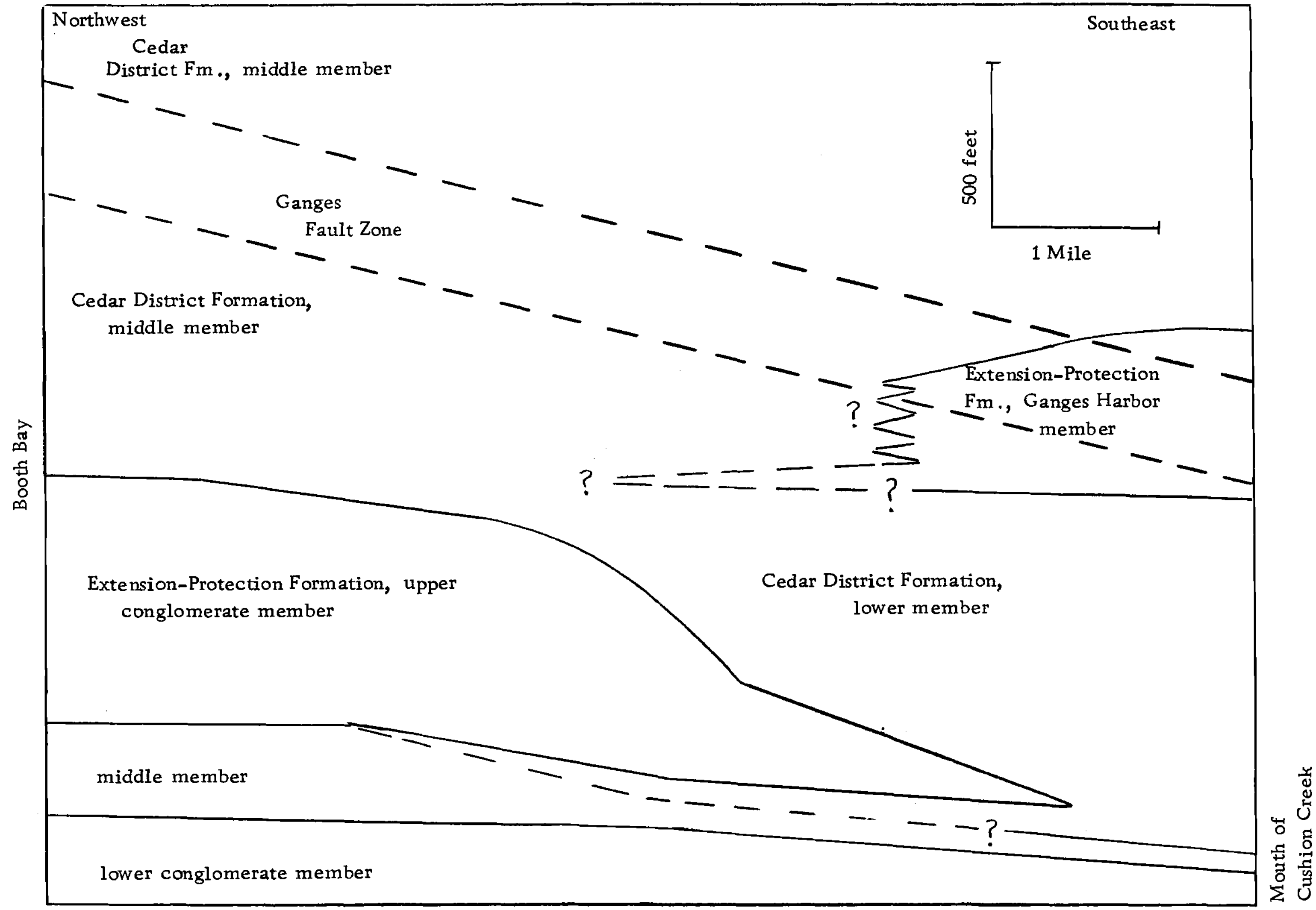


Figure 10. Stratigraphic relationships between Extension-Protection Formation and Cedar District Formation, diagrammatic and in part, inferred.

predominate. It is a grain-supported or orthoconglomerate (Pettijohn, 1957) and clasts are tightly packed, subangular to well rounded. The matrix is moderately to poorly sorted sandstone composed of quartz, feldspar and biotite. Compositionally, the conglomerate is petromict (Pettijohn, 1957); a diversity of igneous intrusive, volcanic, sedimentary and metamorphic lithologies occur.

Sandstone is a minor component of the upper conglomerate member and occupies lenses up to 4 feet thick and 60 feet wide. Also, an interval of sandstone is always present at the top of the member. Sandstones are light gray (N7), fresh, and light gray to light olive gray (5Y 6/1), weathered. They are thick- to very thick-bedded, fine- to coarse-grained, moderately to well sorted, and locally laminated and pebbly.

Intraformational conglomerate is common and consists of angular to rounded dark gray mudstone clasts in a finer conglomerate matrix. Mudstone clasts attain 4 feet in diameter, are commonly micaceous, and locally contain leaf impressions and siltstone, sandstone and pebbly sandstone laminae.

Sedimentary structures are rare in the upper conglomerate member. Broad channeling and cut-and-fill relationships are characteristic (Figure 11). Pebble imbrication is rare, perhaps because clasts tend to be equant in shape. Cuspate or interference ripple

Figure 11. Large scale cut-and-fill in Extension-Protection Formation upper conglomerate member. Note pebbly sandstone channel fill behind geologic hammer. At 728 feet, Measured Section D'-E, Mount Erskine.

marks occur in the uppermost sandstones (roadcut 0.75 miles northeast of Erskine Point).

Ganges Harbor Member. The Ganges Harbor member lies between the lower and upper members of the Cedar District Formation, about 1,000 feet above the top of the southeast extension of the main body of the Extension-Protection Formation (Figure 10). It is confined to the east central part of the island but occupies a stratigraphic position perhaps no more than 200 feet above the top of the upper conglomerate member lying to the northwest on Mount Erskine.

The stratigraphic sequence and thickness of this unit are poorly known. It is intersected by the Ganges Fault zone and stratification is vertical to overturned, severely sheared and locally obliterated. The base of the member consists of about 100 feet of thin to very thick-bedded fine- to medium grained sandstone with mudstone partings. Upward the sequence becomes pebbly and conglomeratic. An interval of mudstone about 50 feet thick and a pebbly mudstone bed 3 feet thick also occur.

Sequence at Cape Keppel. An estimated 200 feet of sandstone and minor conglomerate at Cape Keppel are provisionally correlated with the Extension-Protection Formation. Although paleontologic confirmation is lacking, several aspects favor correlation with the lower Extension-Protection Formation:

1) the sequence overlies a thick mudstone sequence which is largely devoid of sandstone and similar to the Haslam Formation;

2) sandstone composition most closely resembles that of the lower Extension-Protection Formation; there is a very high content of metamorphic rock fragments and chert;

3) pebble composition most closely resembles that of the lower conglomerate member; there is an abundance of gray chert and argillite and a dearth of volcanic and intrusive igneous clasts.

The Cape Keppel sequence exhibits an overall upward coarsening of grain size and thickening of stratification. Coloration is medium light gray (N6) weathered, and medium gray (N5) fresh. Sandstones are tabular, thin to thick-bedded, medium- to coarse-grained, well sorted with angular to subangular grains of quartz, chert, rock fragments, feldspar, magnetite and biotite. The lower part of the sequence contains a few very fine-grained sandstone interbeds. Near the top, thin lenses and channels of pebble conglomerate occur.

Sedimentary structures include lamination, thin trough cross-beds, cross-laminae and scour and fill. A few spherical calcareous sandstone concretions (0.5 to 12 inches diameter) and wood fragments occur.

Depositional Environments

The upper and lower conglomerate members of the Extension-Protection Formation were deposited as the tractive bed load of competent fluvial agents which drained a nearby source of high relief. The upper conglomerate member was deposited either subaerially as an alluvial fan or subaqueously as a gravel wedge at a river mouth. Conclusive evidence of subaerial deposition is lacking. The coarse grain size, tight packing, channeling, and lack of fine-grained overbank deposits suggest transportation and deposition by powerful perennial braided streams. (The Extension-Protection flora indicates a warm temperate climate (Bell, 1957).) Deposition as a basin margin fan adjacent to a tectonically active source area is consistent with the wedge geometry (Figure 10), lateral decrease in clast size, apparent character of fluvial processes, and lateral gradation into an offshore marine facies of the lower Cedar District Formation (Allen, 1970). Intraformational mudstone conglomerates were derived by erosion of contemporaneous mud and record short transport to the depositional site (Smith, 1972). There is very limited evidence for marine deposition in the upper and lower conglomerate members. A single costate pelecypod valve (resembling Lima) was found in the lower conglomerate member near the mouth of Cusheon Creek. Well sorted sandstone and fine pebble conglomerate at the top of the upper conglomerate member could be of either fluvial or shallow marine origin.

The middle member of the Extension-Protection Formation was deposited in both fluvial and littoral environments. Fluvial deposition was by competent streams which deposited and cut a floodplain of sand, gravel and mud. Mudstone was deposited from suspension in abandoned channels or interchannel areas. Highly lenticular sandstone and conglomerate channels with internal cut-and fill are typical of the floodplain environment (Masters, 1967; Heckel, 1972). Tractive transport is recorded by tightly packed conglomerates, cross-bedding, pebbly sandstone, sand waves, and cross-lamination. Interlamination of coarse and fine sandstone is a characteristic fluvial feature which reflects rapid velocity flutuations (Heckel, 1972). Littoral deposits are distinguished by the occurrence of abundant current-oriented thick-shelled marine pelecypod valves (including *Glycimerus*). Large pieces of wood and abundant leaf fossils in coarse sandstones also suggest fluvial or nearshore marine deposition. Deposition of the middle Extension-Protection along a coastline is indicated by the close association of fluvial and shallow marine facies and vertical gradation of the mixed fluvial-shallow marine interval into an offshore marine facies (lower Cedar District Formation).

Cedar District Formation

The name Cedar District Formation was first applied to the marine mudstone sequence which overlies the coal-bearing strata at Nanaimo (Clapp, 1912). On Saltspring and adjacent islands, the Cedar District Formation intertongues with underlying and overlying more coarsely clastic formations. Therefore, a more precise definition of the formation is adopted in order to detail adequately the complex relationships with adjacent stratigraphic units. A working definition of the Cedar District Formation employs the following criteria:

1) the lithology is dominantly mudstone;
2) it is a topographically nonresistant unit which forms valleys, lowlands, bays and inlets;
3) sandstone units also are nonresistant and are composed of mudstone with sandstone beds that are predominantly less than 2 feet thick; the sandstone intervals are laterally restricted (in contrast to De Courcy Formation sandstone bodies).

The Cedar District Formation is divisible into three major informal members on Saltspring Island: lower member, middle member, and upper member. The lower member is in part correlative to the main body of the Extension-Protection Formation and underlies the Ganges Harbor member of the Extension-Protection Formation

(Figure 10). The middle member (formerly Ganges Formation of Clapp and Cook (1917)) overlies the upper conglomerate member of the Extension-Protection Formation and lies below the lowest De Courcy Formation tongue (Kd_1). The upper member of the Cedar District Formation lies between the upper and lower De Courcy sandstones (Kd_1 and Kd_3) and interfingers with Kd_2 on the north limb of the Kulleet Syncline (Figure 22).

Areal Distribution and Thickness

The Cedar District is the most areally extensive formation in the study area. The lower member is restricted to the west central part of the island, and underlies a narrow northwest-trending valley less than 0.25 miles wide which extends for nearly 3 miles inland through Sections 76, 88, and 87 (Plate 1). A thickness of 1,056 feet was measured at the public beach north of the mouth of Cusheon Creek (Appendix I, Measured Section A-B).

The middle Cedar District member underlies the lowland which extends southeast from the south shore of Booth Bay to Ganges village and along the south shore of Ganges Harbor. The actual thickness is unknown but appears to be at least 1,500 feet. An interval 516 feet thick at the top of the middle member occurs along the north shore of Booth Bay (Appendix I, Measured Section F-G).

The upper member of the Cedar District Formation is well exposed at Vesuvius Bay, at Ganges Harbor, and along the northeast coast of Saltspring Island. It underlies the lowland extending northwest from Ganges village to Vesuvius, and the area from Walker Hook northwest through the cultivated and forested area north of St. Mary Lake. The designated type section of the Cedar District Formation occurs at Dodd Narrows near Nanaimo, is more than 1,010 feet thick, and is equivalent in stratigraphic position to the upper member of this study (Muller and Jeletzky, 1970). The upper member is 1,450 feet thick at Vesuvius Bay (Appendix I, Measured Section H-I); a similar thickness exists at Ganges Harbor.

Contact Relationships

All sedimentary contacts between the Cedar District and adjacent formations are conformable and gradational. The abruptly gradational lower contact with the Extension-Protection Formation has been described previously. The upper contact of the middle member, separating sandstones of the lower De Courcy Formation (Kd_1) from rhythmically interbedded mudstones and siltstones of the Cedar District Formation, is exposed about 0.75 miles northwest of the mouth of Booth Inlet and near the government wharf at Ganges on the south side of Grace Point. Northwest of Booth Inlet the contact is drawn at the sharp and planar to loaded base of a one-foot sandstone bed. The lower De Courcy shows an upward thickening and coarsening of sandstone beds. At Grace Point the contact is intercalated and gradational over about 20 feet. The percentage of sandstone and siltstone increase upward as the contact is approached. The transitional interval consists of very thin to thin sandstone beds (0.5 to 12 inches) with mudstone partings.

The lower contact of the upper member, exposed on the west shore of Vesuvius Bay, is arbitrarily picked at the top of a sandstone bed 3 feet thick. The contact is best described as gradational by an upward decrease in sandstone bed thickness and grain size and concomitant increase in proportion of mudstone. The transition from thick- and very thick-bedded De Courcy sandstone to thin-bedded mudstone siltstone and sandstone of the Cedar District Formation occurs over an interval of about 10 feet.

The upper contact of the upper member is exposed on the northeast shore of Vesuvius Bay and the south side of Welbury Point. At Vesuvius Bay this contact is intercalated and gradational over a stratigraphic interval of less than 50 feet. At Welbury Point the contact is sharp and planar with load and groove casts at the base of a very thick (6 feet) coarse-grained sandstone which directly overlies laminated mudstones and siltstones of the uppermost Cedar District Formation. There is no evidence of erosion or angular discordance and the contact is construed as conformable.

Lithology and Stratification

The Cedar District Formation is composed of mudstone, siltstone, and sandstone. It consists typically of rhythmically bedded flysch-like sequences of mudstone-siltstone and sandstone which show a wide variation in the thicknesses and proportions of interbedded lithologies. Several lithofacies which cover the spectrum of vertical and lateral gradations are discussed below.

Mudstone Facies. Much of the Cedar District Formation is composed of mudstone with a minor proportions of rhythmic interbeds (laminae to very thin beds - 0.1 to 2 inches thick) of siltstone and sandstone (Figure 12). This facies comprises much of the middle and appreciable parts of the lower and upper members.

Mudstone is medium gray (N5) to medium dark gray (N3), fresh and weathered. It has a platy tendency and weathers into small flat chips (less than one inch dimension). Mudstone varies from a silty claystone to clayey siltstone. Tubular silt- and sand-filled burrows up to 0.5 inches diameter and tiny clay-filled burrows are common. The latter resemble *Helminthoida*. Also common are calcareous mudstone concretions which are elliptical in cross-section and a maximum of about four inches thick and tens of feet long. Weathered color is generally light gray (N7) but some are pyritic, rusty-weathering, and dark yellowish orange (10YR 6/6). *Inoceramus*

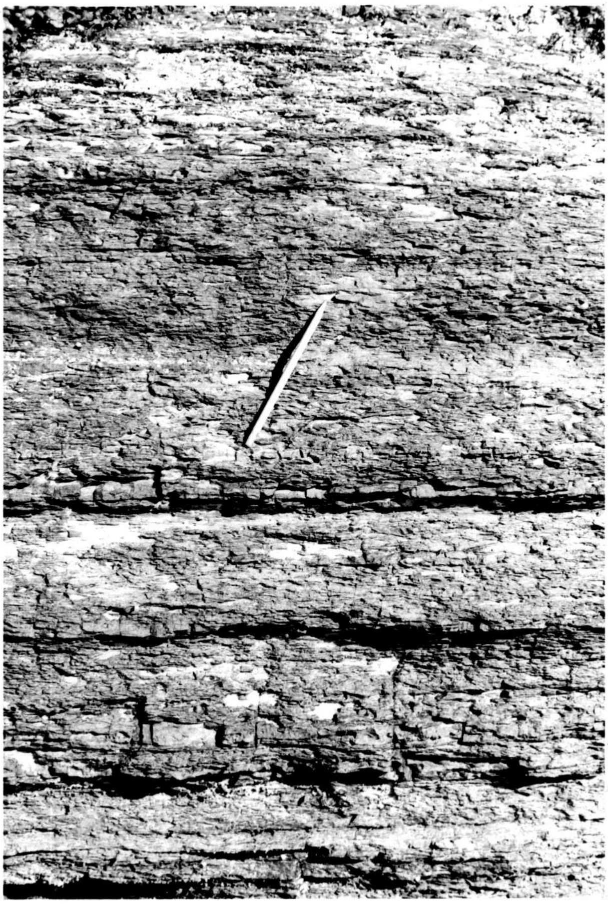


Figure 12. Mudstone with rhythmic siltstone laminae in Cedar District Formation, upper member. Note crushed Inoceramus in incipient concretion at pencil point. Middle of Unit 2, Measured Section H-I, Vesuvius Bay.

valves up to 12 inches long are locally common within the concretions. Mudstone matrix bends around the concretions by arching of the platy parting over and under the calcareous bodies.

On the modern shore platforms, interbedded sandstones and siltstones weather out in relief and create a weakly ribbed surface. Color is light gray (N7) fresh, and light olive gray (5Y 6/1) to olive gray (5Y 4/1) weathered. Most of the interbeds are laterally continuous in outcrop, and some have been traced for hundreds of feet. However, lenticular laminae are common. Sandstone-siltstone beds have sharp bases with minute load casts, and gradational upper contacts. Sandstones are fine- to very fine-grained, moderately sorted, and locally calcareous.

Sedimentary structures include very thin parallel lamination, cross-lamination and sinusoidal ripple lamination (Jopling and Walker, 1968), and parting lineation. Many of the sandstone and siltstone laminae are indistinctly cross-laminated. Sole marks consist of abundant burrows and load casts, groove casts, and rare flute casts. Soft sediment deformation is common: contorted laminations, over-steepened foreset laminae, and flame structures occur. Small (less than 0.5 inches) angular mudstone clasts occur in some beds.

At some localities (as on the southwest side of Welbury Point), the interbeds consist of a row of asymmetrical ripples on a bedding plane or a set of ripples on top of parallel lamination. The ripples have sharply truncated stoss sides, wavelengths of 2 to 8 inches, and amplitudes of 0.5 to 1.0 inches. The foresets are invariably inclined to the northwest, and are overlain by siltstones or mudstones with parallel, contorted, or sinusoidal lamination.

Thin-bedded Flysch-like Facies. A major component of the Cedar District Formation are flysch-like sequences of repetitively interbedded mudstone-siltstone-sandstone in which the thickness of sandstone-siltstone beds is 2 to 24 inches. The proportion of sandstone-siltstone to mudstone is variable, but ranges up to at least 80 percent. Such sequences form strongly ribbed shore platforms such as those developed along Vesuvius Bay (Figure 13), northwest of Fernwood, and north of the mouth of Cusheon Creek.

Individual sandstone-siltstone beds are laterally persistent and rarely lenticular. They sometimes succeed each other without intervening mudstone such that the top of the underlying bed is deformed and truncated. Lower bedding surfaces of sandstone-siltstones are invariably sharp and mostly planar although load and flame structures are common. Groove and flute casts exist but are not abundant. Upper contacts are of variable character, ranging from sharp and planar to gradational. Most beds are composed of fine-grained sandstone to siltstone although grain size ranges up to coarse sand.

The sandstone and siltstone beds possess a variety of internal sedimentary structures. Wherever a definite grain size distribution

Figure 13. Shore platform developed on Cedar District Formation upper member. De Courcy Tongue 3 underlies the ridge at the backshore. Unit 4, Measured Section H-I, Vesuvius Bay.

can be observed, the finer grains are concentrated at the top of the bed and the coarser grains below. Commonly, a continuous size gradation exists and some sequences exhibit repeated normal grading (Figure 14).

Complete Bouma sequences of sedimentary structures occur, but most beds contain incomplete sequences of the base-cut-out type (Bouma, 1962). (For example, see Appendix I, Measured Section A-B, Interval 209-138.) Ripple cross-lamination and sinusoidal ripple lamination are generally closely associated and cross-lamination was observed to pass upward through an intermediate structure (asymmetrical undulating lamination (Jopling and Walker, 1968) into sinusoidal ripple lamination.

There is a variety of post-depositional sedimentary structures in the thin-bedded flysch-like facies. Soft-sediment deformation is expressed as contorted lamination (very common in the fine-grained tops of beds), overthrust faults, small sandstone dikes (less than 14 inches long), ball-and-pillow structure, and load casts. Overturned and recumbent folds which involve a single bed occur and record slumping on paleoslopes. Mudstone and siltstone rip-ups are common in sandstone beds and reach a few inches in length.

Impure limestone is a minor component of both the mudstone and thin-bedded flysch-like facies. Limestones exist as thin beds and lenses which resemble silty micrite and effervesce vigorously

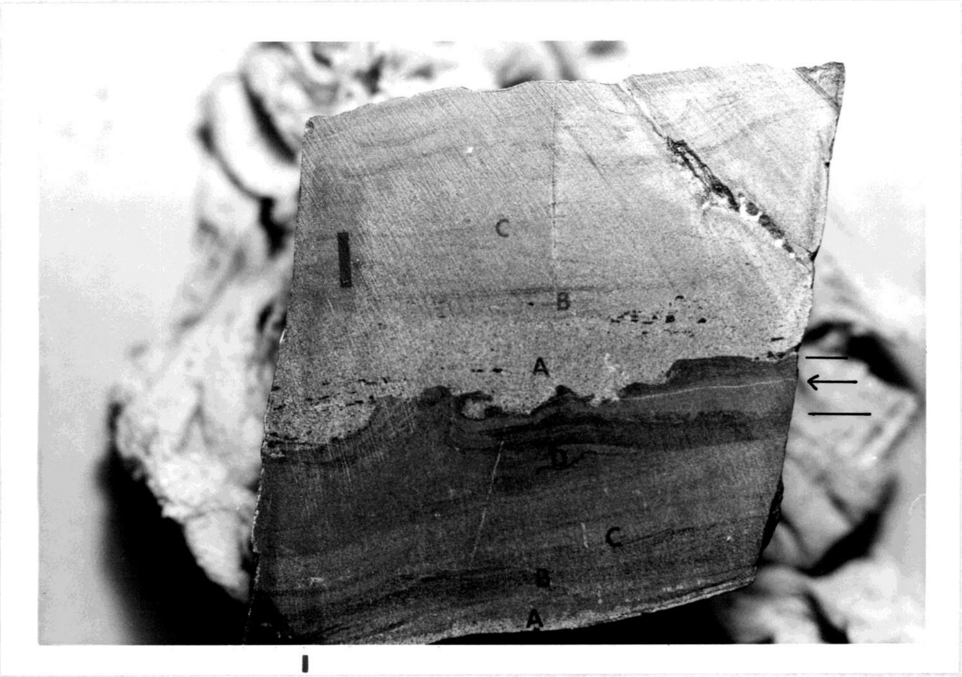


Figure 14. Three graded beds showing possible Bouma divisions of primary structures. Note angular mudstone rip-up clasts in base of upper bed and deformed middle bed (arrow). Bar is nine millimeters long. Measured Section A-B, lower Cedar District Formation.

when dilute acid is applied. Weathered surfaces are light gray (N7) to yellowish gray (5Y 7/2); fresh surfaces are medium dark gray (N4) to olive gray (5Y 4/1). The beds are often thinly laminated and mottled by minute clay-filled burrows which resemble Helminthoida.

Platy Sandstone-Siltstone Facies. The platy facies, an allusion to the well-developed platy splitting property of sandstones and siltstones, is a minor but distinctive component of the Cedar District Formation. The suite of sedimentary structures and interbed lithology serve to distinguish it from thin-bedded flysch-like sequences.

This facies is best exposed on the coastline 1.25 miles northwest of Fernwood (Lot 8), nearby along the gravel road in the northwest end of Lot 7, and in the basal few feet of the upper member at Versuvius Bay. The platy facies consists of interbedded parallel-sided sandstone, siltstone, and mudstone. Sandstone beds have sharp and planar lower and upper surfaces and range from 0.5 to 20 inches thick. Normal grading and sole marks, except for small load casts, are absent. Lamination is ubiquitous and is the result of concentration of silt and flat-lying mica on bedding planes. Cross-lamination also occurs.

Sandstone is fine-to very fine-grained, well sorted, and contains carbonate cement and minor intergranular matrix.

Figure 15. Graded bed (A) showing sharp base, mudstone rip-up clasts, and platy undulating (sinusoidal ripple?) lamination at top. Below are cross-laminated sandstone-siltstone beds which record current flow to the northwest (right). Lens brush case is 3 inches long. Upper Cedar District Formation about 0.75 miles northwest of Walker Hook.

Interbeds consist of micaceous silty mudstones and siltstones which are typically thinly laminated (more than 25 per inch), or discontinuously laminated and thinly cross-laminated. Locally, small scale ripples with linear to anastomosing crests and interference ripples can be identified.

Thick-bedded Sandstone Facies. At some localities, the thin-bedded facies shows a vertical gradation into sequences dominated by thick- to very thick-bedded sandstone beds (2 to 7.4 feet). Sandstones are light olive gray (5Y 6/1) weathered, and medium light gray (N6) fresh. They range from very coarse- to very fine-grained, are poorly to moderately sorted, and are composed of angular to subangular grains of quartz, feldspar, muscovite, biotite and rock fragments.

At Vesuvius Bay, at least 70 percent of the thick sandstone beds are normally graded (Unit 3, Measured Section H-I) and one bed shows coarse-tail grading (dispersed pebbles confined to the base of the bed). Most beds are characterized by a structureless or faintly laminated lower three-fourths which is succeeded by an interval of normal grading with the upward-fining of grain size occurring over a few inches from coarse- or medium-grained sandstone to silty mudstone. Fine-grained upper parts of beds are thinly laminated and possess a platy parting, or/and contain sinusoidal ripple lamination and less commonly cross-lamination (type A). Commonly normally graded beds supersede each other without intervening mudstone.

Sandstone bases are always sharp and mostly planar. Where minor relief occurs it is the result of load and groove casts, erosion of underlying mudstone and siltstone, or deposition upon irregular topography of slumped beds. Most beds are parallel-sided and laterally continuous in outcrop. However, rare beds with convex lower surfaces channel into subjacent strata and wedge out within a few tens of feet.

Commonly incorporated in and sometimes constituting an appreciable part of thick sandstone beds are numerous mudstone clasts and large ripped-up sheets of thinly interbedded to interlaminated mudstone, siltstone and sandstone, or siltstone apparently derived from the top of the subjacent normally graded bed. The rip-ups (which attain 25 feet in length and 1 foot thick) are folded, rolled, and at places still connected to underlying strata. Where fine-grained tops of beds are ripped up, amalgamation occurs (Walker, 1966). Such amalgamated beds have been traced laterally into distinct beds separated by the intact top of the subjacent bed. Some beds consist of a chaotic mixture of intraformational clasts which are enclosed in a heterogeneous matrix composed of discrete sandstone, mudstone and sandy mudstone regions (Figure 16).

Pebbly mudstone (paraconglomerate of Pettijohn (1957)) occurs in the Cedar District Formation upper member at two localities, both

Figure 16. Chaotic bed consisting of medium- to coarse-grained sandstone with discrete masses of muddy sandstone and chaotically mixed mudstone and sandstone (under hammer). Stratigraphic up is to the left. Upper part of unit 3, Measured Section H-I, near Vesuvius Ferry landing.

on the northeast coast of Saltspring Island. An isolated end of the oyster lease, Lot 17; 0.75 miles northwest of Walker Hook a bed occurs in association with thick-bedded sandstones. The pebbly mudstone beds are 10 to 15 feet thick and contain randomly distributed sand, pebbles and cobbles suspended in a mudstone matrix (Figure 20). Contorted mudstone, siltstone and very fine-grained sandstone rip-ups also occur. Pebbles and cobbles (maximum diameter 5 inches) are mostly well rounded basic to intermediate volcanics, gray chert, argillite and calcareous mudstone concretions. They are the largest extraformational clasts which occur in the Cedar District Formation.

Fossils

Organic remains are overall notably rare in the Cedar District Formation. However, large delicate valves, some articulated, of *Inoceramus* are locally abundant in concretions of the mudstone facies (Appendix I, Measured Section F-G; Measured Section H-I', Unit 2). Elsewhere, carbonaceous flakes, rare *Inoceramus* fragments and crushed *Baculites* occur in mudstone interbeds.

Trace fossils are more common than body fossils. Some fine-grained tops of thick sandstone beds are extensively burrowed, whereas lower parts of corresponding beds lack or contain few burrows. Along the coastline northwest of Fernwood, numerous and exceptional specimens of Thalassinoides (Figure 17) crowd siltstone and fine-grained sandstone bedding planes (Chamberlain, written communication, 1975). Minute, dark, clay-filled burrows are widespread. They resemble Helminthoida and consist of meandering and looping tubes, crescents and lenses about 1 millimeter in diameter. They occur in mudstones and siltstones of all facies and are common to laminated micritic lenses and the tops of graded beds.

Discussion of Depositional Processes

A variety of depositional processes is indicated by the textures, scale and geometry of stratification, and primary structures in the Cedar District Formation. Mudstone is interpreted to be a product of the "normal" rain of sediment carried in suspension. Variations in the proportion of silt admixture in the mudstones might be a consequence of proximity to sediment source such as at river mouths, distribution by marine currents, or homogenization by benthic fauna after deposition. Widespread and locally thorough burrow mottling suggests a slow sedimentation rate. Calcareous mudstone concretions are probably of early diagenetic origin as suggested by arching of the enclosing mudstone over and under them, enclosure of undeformed fossils, and their occurrence in contorted intraformational rip-ups (Rahmani, 1970).

Figure 17. Thalassinoides in fine-grained, platy sandstone of upper Cedar District Formation. Coastline 1.25 miles northwest of Fernwood Point.

The platy facies records selective deposition of a limited range of grain sizes. Current action is documented by cross-lamination, ripples and parting lineation. Abrupt thin interlaminations of silt and clay and 'mud' and silt ripples are unique to this facies. Perhaps rather continuous agitation prevented the settling of clay and fine silt during deposition of the well-sorted sandstones.

Many of the graded sandstone-siltstone beds of the Cedar District Formation resemble the deposits of turbidity currents (Kuenen and Migliorini, 1950). Several other authors have interpreted turbidite sequences in the Cedar District Formation (Rahmani, 1968; Muller and Jeletzky, 1970; Simmons, 1973). Possible turbidite features include: repeated normal grading, laterally continuous parallel-sided beds, sharp bases and diffuse or gradational upper contacts, flute and groove casts and Bouma sequences of internal structures. There is a lack of certain structures such as multiple-scour-and-fill, linear-crested ripple marks, and extensive (more than 1 inch thick) cosets of ripple-drift cross-lamination (climbing ripples).

Turbidites are interpreted to be the deposits of underflows of sediment-charged water which, deriving kinetic energy from gravity, move downslope as discrete fluid masses because of a greater bulk density than the surrounding water. Repeated normal grading in relatively coarse-grained layers which have sharp lower contacts, and alternate with layers of fine mud, is characteristic of deposition by turbidity currents (Dott, 1963). Each turbidite bed represents one event of rapid deposition from a waning density current. The normal grading and sequence of sedimentary structures reflect slowing of the current during sedimentation (Walker, 1965). Many of the graded thin- to very thin-sandstone-siltstone beds are virtually identical to recent deep marine turbidites. (For example, see Bouma and Brouwer (1964) Figure 1, page 251). The predominance of base-cut-out Bouma sequences (B-E, C-E, D-E) in very thin- to thin-graded beds is characteristic of distal turbidites and deposition within the lower flow regime (Walker, 1967).

Convincing evidence has been presented which indicates that some flysch-like sequences of normally graded beds, containing Bouma sequences of internal structures, were deposited in a pro-delta environment by an across-slope ocean bottom current system (Hubert, and others, 1972). Thus, some Cedar District sequences are probably of turbidite origin, for example, in the lower member (Measured Section A-B) there is a general coincidence in orientation of soft-sediment overfolding and current-formed structures which suggests that the currents flowed down the paleoslope. Other sequences may contain a significant proportion of sandstone beds which were reworked from turbidites or transported and deposited entirely by other types of bottom currents (Hsu, 1964). There are

Figure 18. Sandstone bed with large rip-up sheets of thin-bedded sandstone-siltstone-mudstone. Bed is five feet thick. Stratigraphic up is to the right. Unit 4, Measured Section H-I, Vesuvius Bay.

still no absolute criteria to distinguish between turbidites and non-turbidites and it is becoming increasingly apparent that the term turbidite has been overused in interpretation (Bouma, 1972). Therefore, the interpretation of turbidity current deposition is not meant to encompass all sandstone-siltstone beds of the Cedar District mudstone and thin-bedded flysch-like facies.

Several distinct types of closely associated beds in the Cedar District Formation can be attributed to a continuum of gravity-induced depositional processes which span the realms of turbulent fluid flow and plastic mass flow (Dott, 1963): normally graded sandstone-siltstone beds; normally graded beds with thick A-divisions and large intraformational clasts; pebbly mudstones; chaotic beds with sandstone and mudstone matrix elements; and prolapsed beds (penecontemporaneous recumbent folds). Prolapsed bedding (Figure 19) and chaotic beds (Figure 16) which lack normal grading and contain discrete regions of mudstone and sandstone as matrix elements and clasts, behaved plastically during downslope movement as indicated by partial retention of initial stratification. Apparently, rate of shear and turbulence were not sufficient to entirely destroy cohesion and cause dilution of the viscous mass by in-mixing of water. In contrast, thick, graded beds passed beyond the plastic state (liquid limit) into viscous fluid flow during which turbulence destroyed stratification and thoroughly mixed mud and sand. Lamination,

Figure 19. Prolapsed bedding in mudstone, siltstone, fine-grained sandstone sequence indicating slump toward the north (oblique left). Point of hammer lies slightly above axial plane. Unit 4, Measured Section H-I, Vesuvius Bay.

cross, lamination, and sinusoidal ripple lamination prove that current action and at least partial suspension transport occurred.

Many of the thick, coarse-grained, graded sandstone beds display characteristics of rapid deposition as fluidized sediment flows (Middleton and Hampton, 1973) and/or proximal turbidites (Walker, 1967). They contain Bouma sequences of structures. The A-divisions (basal structureless or graded division) are dominant. They range from pebbly very coarse to fine-grained sandstone and some exceed 5 feet in thickness. At Vesuvius Bay (Measured Section H-I, Unit 3), A, AB, and ABE Bouma divisions are abundant, but AE, ABCE, and others also occur. The B- and C- divisions, lower interval of parallel lamination and interval of current ripple lamination, are composed of very fine-grained sandstone to siltstone. These thin upper divisions are to varying degrees truncated or ripped-up and incorporated into the A-division of the overlying bed. The thickness, coarse grain size, dominance of A-divisions, abundant evidence of erosion and amalgamation,and occurrence (although rare) of channelized beds strongly suggest proximal turbidite deposition (Walker, 1967).

The large contorted rip-ups are contrary to accumulation of the enclosing sandstones by normal tractive processes. Rather, emplacement as a viscous fluid seems probable and necessary for the sand to have engulfed, transported and locally preserved in-place the

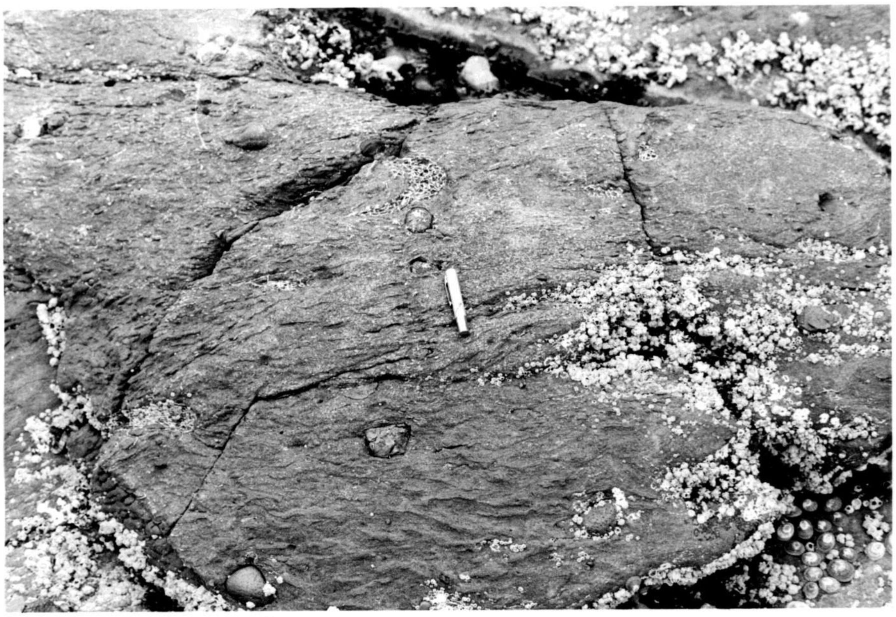


Figure 20. Pebbly mudstone in Cedar District Formation upper member 0.75 miles northwest of Walker Hook. Lens brush case is three inches long.

sheets of siltstone-sandstone-mudstone. Such outsized clasts could have been carried in a manner similar to large boulders in subaerial mudflows. Therefore, the thick Bouma A-divisions which contain large intraformational clasts may have been emplaced as viscous suspensions or flowing-grain layers (Sanders, 1965) which moved at the base of fully turbulent density-driven turbidity currents.

Pebbly mudstones, which are characterized by a homogeneous but unsorted mixture of matrix-supported clasts, exemplify a gravity flow in which movement was arrested at a stage intermediate between plastic mass flow (chaotic and prolapsed beds) and viscous fluid flow (turbidite and grain-flow) (Dott, 1963; Crowell, 1957). No extra-formational clasts which even approach the size of those in the pebbly mudstones occur elsewhere in the Cedar District Formation. Apparently, the submarine debris flows were able to travel considerable distances. The close association of prolapsed bedding, chaotic beds, pebble mudstone, grain-flow and proximal turbidite (fluidized sediment flows) beds suggests a genetic relationship. It is now well established, by empirical, experimental, and theoretical methods that subaqueous slumps can generate turbidity currents (Hampton, 1972).

Depositional Environments

Most of the Cedar District Formation records offshore marine deposition in delta-front slope and prodelta environments. The combination of sedimentary textures, structures, stratification, and fossils (especially in the middle member and mudstone-dominated parts of the upper member) is like that of modern delta-front and prodelta sediments. (For example, see Shepard (1960), Figure 7-C, page 67.) The high silt content of Cedar District Formation mudstones is not typical of deep marine hemipelagic muds, but rather reflects proximity to a major sediment source. (Characteristics of selected modern delta-front and prodelta sediments are given in Table 3.)

The precise environment of deposition of the proximal turbidites and associated chaotic and prolapsed beds is uncertain. However, the inferred processes of deposition and preservation imply slope-controlled sedimentation, and deposition in quiet water, respectively. The association of dispersed and contorted clasts suggests mass flow as a result of slumping (Klein and others, 1972). In the delta-front environment, depositional slope is relatively high and consequently favorable for downslope movement of turbidites generated by slumping or rapid influxes of sediment directly from distributary mouths. For example, slopes of two degrees are

Table 3. Sediments of selected delta-front and prodelta environments.

Location	Sediment Characteristics
Fraser River Delta (Johnston, 1922; Mathews and Shepard, 1962)	Very fine sand, silt to clayey silt; lamination, lenticular and cross-lamination; mica, wood and plant fibers; few forams; base of slope about 600 feet.
Mississippi River Delta (Coleman and Gagliano, 1965; Shepard, 1960)	Fine sand, silt to silty clay; thin-bedded, parallel and ripple lamination, cross-lamination; plant fibers; burrows.
Niger River Delta (Allen, 1970)	Outer platform: evenly laminated clayey silt, clean coarse silt, very fine sand; parallel lamination, cross-lamination, organic mottling; graded sand layers 2 to 6 inches thick; depth about 6 to 60 feet. Slope: interbedded clayey silt (8 to 12 inches thick) and graded coarse silt 0.5 to 2 inches thick; bioturbation; base of slope about 130 feet.
Rhone River Delta (van Straaten, 1959; Oomkens, 1970)	Interlaminated muddy sand and sandy mud; can correlate layers over distances of kilometers; commonly burrowed; base of slope about 230 feet?
General Criteria (Shepard, 1964)	Very fine sand and silt interlaminated with silty clay; excessive mica; rare forams.

are common at the front of the Fraser River Delta (Terzahgi, 1962). Mass gravity movements are quite common to rapidly deposited metastable sediment of delta-front slopes (Dott, 1963) and prodelta turbidites have been widely reported (Walker, 1966; Lineback, 1968; Selley, 1970). Slumping may be an inevitable consequence of progradation into relatively deep water.

The proximal turbidite, sediment flow, and slump beds are believed to have been deposited along an active delta-front and were perhaps "funneled" basinward onto the slope, base of slope (Stanley and Unrug, 1972) or basin floor by way of delta-front channels (Shepard and Dill, 1966). Because there is no depth restriction on the operation of turbidity currents, the preservation of their deposits indicates only that deposition was below wave base. Delta-front slope sediments of the Fraser River Delta consist of thin lenses of disturbed (slumped) material in a matrix of undisturbed sediment (Terzahgi, 1962) and provide a possible model of the depositional environment of the similar Late Cretaceous Cedar District Formation beds.

The Cedar District fauna is compatible with marine delta-front to prodelta deposition at outer shelf to upper bathyal depths. The modern habitats of extant genera collected from the Cedar District Formation are primarily littoral and shelf (neritic) (Table 4).

Figure 21. Lower Cedar District Formation graded sandstone bed of probable turbidite origin. Bed at upper right is four feet thick. Measured Section A-B, outer southeast Ganges Harbor.

Table 4. Probable habitat of extant molluscan genera from the Cedar District Formation of the Nanaimo Basin.

Fossil	Habitat of Modern Genus
Pelecypoda:	
Cuspidaria	135 to 9,000 feet
Laevicardium	Intertidal to 460 feet
Lucina	Intertidal to 135 feet, in sand
Nucula	30 to 6,000 feet
Thracia	Intertidal to 460 feet, nestling
Gastropoda:	
Capulus	135 to 170 feet on the clam Pecten diegensis
Cypraea	Intertidal to 135 feet, on rocks
Epitonium	Intertidal to 1,200 feet

Faunal source: Usher (1949).

Ecology: Keen and Coan (1974).

Ammonites suggest open communication with the Pacific Ocean (Muller and Jeletzky, 1967). Foraminifera from the type section at Dodd Narrows indicate bathyal water depths (2,400 to 3,000 feet), equivalent to or deeper than the present Strait of Georgia (Sliter, 1973). However, as suggested by paleocurrent data and facies variation, the type section probably was deposited in deeper water than the correlative upper Cedar District of Saltspring Island:

1) Cedar District paleocurrents flowed toward the west, northwest (Figure 60) and north (Simmons, 1973) and indicate that the Dodd Narrows section, which is located 20 miles northwest of Saltspring Island, was probably located basinward from the study area during Late Cretaceous time.

2) The type section at Dodd Narrows consists of a much different lithofacies than the upper Cedar District of Saltspring Island. The type section consists of unfossiliferous mudstone and lacks sandstone beds (Muller and Jeletzky, 1970), even those of turbidite origin (Rahmani, 1968). Conversely, the upper Cedar District of Saltspring Island contains abundant thick bedded sandstones and probably was deposited closer to the sediment source and therefore in shallower water.

Dr. C. Kent Chamberlain of Ohio University reports on trace fossils from the upper Cedar District Formation northwest of Fernwood:

> Specimen 150/from the Cedar District Formation probably is Thalassinoides which is an "unpelleted" form of Ophiomorpha. These particular ones do not show the complex maze commonly seen nor the regular 120 degree branching. Yet some show a hint of "pelleting" and meniscate back filling. The longer and less regular branching forms are most common in deeper occurrences of Thalassinoides which is outer shelf to upper bathyal. (Chamberlain, written communication, 1975)

Thalassinoides occurs in offshore facies of rocks of Late Cretaceous age in central Utah (Howard, 1966) and has more recently been reported from the Campanian of southern California in a "mass grain-flow" lithofacies which contains Forminifera of outer shelf to upper bathyal environments (Fern and Warme, 1974).

Trace fossils resembling those from the Northumberland Formation which were identified by Chamberlain (1975) as Helminthoida, are widespread in the Cedar District Formation. Helminthoida is most common in abyssal waters, common in Deep-Sea Drilling Project cores, and typically found in flysch sequences. Abundant trace fossils suggest an oxygenated environment with open marine circulation (Chamberlain, 1971).

De Courcy Formation

The name De Courcy was first applied to the sandstones which overlie the Cedar District Formation and form the De Courcy Islands (Clapp, 1912). According to Muller and Jeletzky (1970), the De Courcy Formation is "the basal continental to littoral clastic deposit of the third cycle of deposition."

On Saltspring Island, the De Courcy Formation consists of several sandstone bodies, inferred to be tongues, that extend from the much thicker sandstone and conglomerate body developed to the southeast (Hudson, 1974; Sturdavant, 1975) and east (?). The De Courcy and Cedar District Formations collectively form a thick interval of intertonguing sandstone and mudstone. Because of the complex stratigraphic relationships within the thesis area, some rules for differentiation of De Courcy sandstone bodies from sandstone intervals of the adjacent mudstone formations were adopted:

1) the De Courcy Formation is composed predominantly of sandstone (and elsewhere conglomerate), which is thick- to very thick-bedded (2 to greater than 4 feet thick);
2) De Courcy Formation tongues are laterally extensive on a scale of thousands of feet and form resistant topographic features such as ridges, cuestas and headlands.

As so defined and differentiated, the De Courcy Formation of the thesis area consists of 4 members. The lower De Courcy Formation (Tongue 1) separates the middle and upper members of the Cedar District Formation. This sandstone body was first correlated (by lithology and position in sequence) with the Protection sandstone of the Nanaimo coal fields (Clapp and Cook, 1917). The Southey Point member (Kd_2) of the De Courcy Formation interfingers with the upper part of the upper Cedar District Formation. The upper De Courcy is composed of two tongues which overlie the upper Cedar District Formation. Tongue 3 separates the upper Cedar District and lower Northumberland Formations. De Courcy Tongue 4 is developed in the lower Northumberland Formation.

Areal Distribution and Thickness

De Courcy Tongue 1 (Kd_1) holds up a narrow ridge which parallels the north shore of Booth Bay and forms the southwest shore of Vesuvius Bay. Most probably an extension of the same sandstone body forms Grace Point in Ganges Harbor and isolated sandstone outcrops to the northwest between Ganges and Booth Bay. A thickness of 292 feet was measured at Booth Bay (Appendix I, Measured Section F-G). About 200 feet of sandstone occur 2 miles to the east along Lower Ganges Road.

The Southey Point member (Kd_2) (Figure 25) crops out only at the northernmost tip of the study area where it is 348 feet thick (Measured Section K-L). The body is replaced laterally to the south and southeast by a thin-bedded Cedar District interval.

De Courcy Formation Tongue 3 (Kd_3) is best exposed at Dock Point, Stone Cutters Bay, and Welbury Point. It forms a prominent cuesta dip slope which extends from Stone Cutters Bay to the north shore of St. Mary Lake. To the south it forms the narrow ridge trending southeast of Dock Point for two miles and extending for 5 miles northwest of Welbury Point. The Chain Islands, in Ganges Harbor, are probably repetitions of the De Courcy Tongue 3. Rapid lateral thickness changes are characteristic of the De Courcy sandstones. The thicknesses of Kd_3 at Dock Point and Stone Cutters Bay are 62 feet and 215 feet, respectively (Figure 22). At Welbury Point, Kd_3 is 262 feet thick (taped thickness) but shows variable thinning and thickening along strike to the northwest.

The uppermost De Courcy body, Kd_4, is confined to the northwestern part of the Island. The thickness is 120 feet where it forms the west side of Stone Cutters Bay (Measured Section K-L) and a cuesta dip slope extending southeast to the north end of St. Mary Lake. The body wedges out east of the lake. Kd_4 also forms the west shore of Duck Bay where the thickness is 144 feet (Measured Section I'-J), but apparently wedges out within one mile to the southeast.

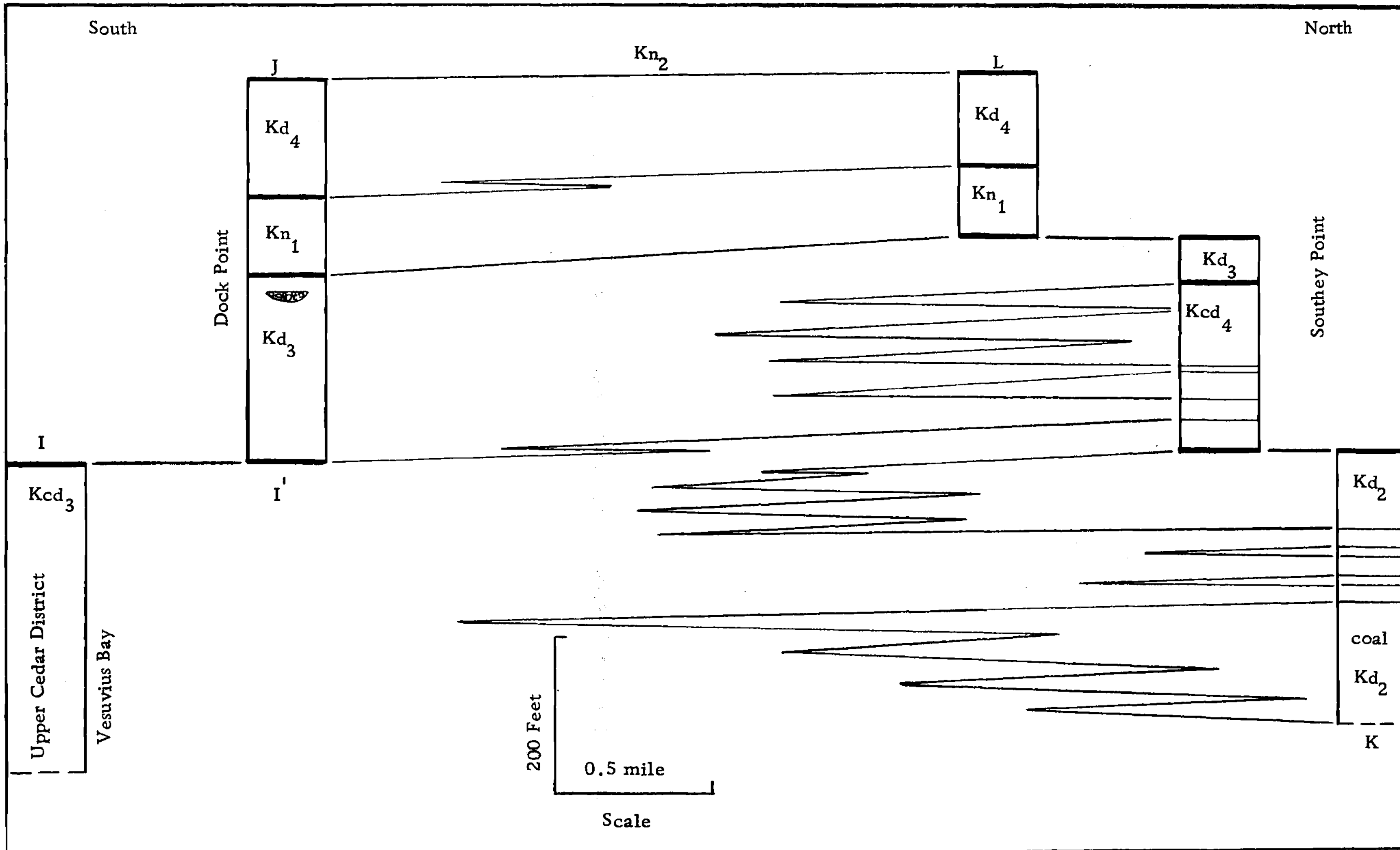


Figure 22. Correlation of upper DeCourcy sandstone bodies across the Kulleet Syncline, perpendicular to paleocurrent flow directions.

Contact Relationships

The lower and upper contacts of De Courcy Tongue 1 are gradational and have been discussed previously (see Cedar District Formation, Contact Relationships).

Contacts between the Southey Point member (Kd_2) and the upper Cedar District Formation are marked by thick intercalated zones in which bedding thickness and lithologic proportions are of intermediate character. The upper contact of Kd_2, exposed 0.5 miles south of Southey Point, is transitional over a stratigraphic interval of about 170 feet (Measured Section K-L).

The lower contact of De Courcy Tongue 3 with the uppermost Cedar District Formation has been described previously. The upper contact with the lower Northumberland Formation is also typically intercalated and marked by the occurrence of the thin-bedded platy sandstone and siltstone facies as described under Cedar District Formation. The upper contact is well exposed on the northeast side of Welbury Point (Measured Section O-P) where an upward-fining and thinning occurs over about 20 feet from thick-bedded De Courcy sandstones, through the thin-bedded platy facies, to mudstone and very thin-bedded siltstone of the Northumberland Formation. At Dock Point this contact is very sharp and planar at the top of a 30-foot sandstone, but again a thin interval of the platy facies comprises the basal Northumberland Formation.

Contacts between the Northumberland Formation and De Courcy Tongue 4 are similar to those already described. The lower contact is sharp, planar, and conformable where exposed in Stone Cutters Bay. The upper contact is gradational with the intercalated transition occurring over a few feet or tens of feet. It is exposed in Duck Bay where the platy facies is developed (Measured Section I'-J) and also exposed on the northwest coast opposite Idol Island (Measured Section K-L).

Lithology and Stratification

The De Courcy Formation is composed of sandstone with subordinate siltstone, mudstone, conglomerate and coal. Sandstones are mostly thick- to very thick-bedded (range from a few inches to 33 feet thick, but are primarily 2 to 10 feet thick) and separated by partings and thin beds of fine- to very fine-grained sandstone, siltstone and mudstone. At least some beds are laterally persistent for thousands of feet.

Sandstones range from fine- to very coarse-grained, average medium-grained, and locally contain matrix-supported very fine to fine pebbles. Weathered color ranges from light gray (N7) and light olive gray (5Y 6/1), to yellowish gray (5Y 7/2). Color of fresh surfaces is medium gray (N5) to medium light gray (N6). Honeycomb and cavernous weathering is common to coastal exposures in the upper tidal to "spray zone."

Lower surfaces of sandstones are invariably sharp and where the interbeds are mudstone or siltstone, commonly possess directional sole marks. Groove casts (up to at least 1 foot wide and 20 feet long) are most abundant and several generations commonly occupy a single bedding plane. Load casts and organic burrows are also abundant. Flute casts, prod casts (Figure 23), current crescent casts, ripply casts and frondescent marks (Figure 24) also occur. Where structures overlap, it is apparent that groove casts predate load casts. Sole markings are magnificantly displayed in abandoned stone quarries (circa 1862) on the southwest side of Dock Point and north shore of Booth Bay. Upper surfaces of sandstone beds are sharp and planar, gently undulating, or gradational into the fine-grained interbed. Some upper surfaces possess hummocky ripple marks, perhaps interference ripples, consisting of circular to oval mounds and depressions. Wavelengths are 3 to 8 inches and amplitudes 1 to 3 inches.

Sandstones are texturally immature to submature (Folk, 1951); fine-grained matrix is commonly conspicuous; sorting is usually moderate to poor; grains are mostly angular to subangular and composed of quartz, feldspar, muscovite, biotite, and rock fragments.

Figure 23. Sole marks in lower part of De Courcy Tongue 1. Note tubular burrows, and the prod cast (above pencil) which indicates current flow toward the northwest (lower left). 1.25 miles northwest of Ganges village.

Figure 24. Frondescent marks and groove casts indicate transport to the northwest and west (left). De Courcy Tongue 3, Measured Section I'-J, stone quarry near Dock Point.

Many sandstone beds appear internally structureless or have a blocky to flaggy parting caused by concentrations of flat-lying mica, carbonized plant material, or parting lineation. However, other internal structures are widespread and locally abundant, but usually most evident only on etched outcrops in the tidal or "spray zone." Plane parallel lamination (3 per inch) is most common and results from interlamination of coarse and fine sandstones and 2 to 6 feet wide, and up to 10 feet long. Thin lenses and channels of fine pebble conglomerate occur at a few localities such as Dock Point (Kd_3), Stone Cutters Bay (Kd_3), and the headland opposite Goat Island in Ganges Harbor.

Other primary structures include scour-and-fill, low-angle cross-bedding, normal and reverse grading, dish structure, contorted lamination, flame structure, and sinusoidal ripple lamination (wavelength 12 inches, aplitude 1 to 3 inches).

Spherical to ellipsoidal calcareous sandstone concretions are common and weather out in relief. They range from less than one to several feet in diameter and tend to be concentrated in thin stratigraphic intervals which parallel the overall bedding. Angular to rounded mudstone and siltstone rip-ups, occur and range up to about 1 foot in length.

Trace fossils are very common and abundantly preserved as sole marks. They consist of unornamented, curving and crossing convex hyporeliefs (Howard, 1966). Probably the same trace is seen in cross-section within sandstone beds as meandering, oval, sand-filled tubes 0.5 to 1.0 inches in diameter which have an argillaceous lining. These traces are identical to planolites of the Comox Formation. Vertically oriented tubes are abundant in some beds at Dock Point. Body fossils are notably rare in the De Courcy Formation. Except for one possible crustacean carapace, faunal remains are restricted to a few disarticulated Inoceramus valves and molds.

Interbeds are less resistant to weathering than the thick sandstone beds. They consist of silty micaceous mudstone, siltstone, and very fine- to fine-grained sandstone, and range from thin partings to about 36 inches thick. Color is light olive gray (5Y 6/1) to very light gray (N8) weathered, and very light gray to medium light gray (N6) fresh. Some interbeds display subtle lateral thickness variations as a result of loading and probable truncation. Sandstones are generally thinly laminated (about 20 per inch), platy, and moderately to well sorted. Siltstones and mudstones commonly bear an abundance of coal flakes (to 3 inches long), carbonized wood fragments (to 12 inches long), and carbonized herbaceous debris resembling reeds, and conifer foliage. Meandering burrows also are common. Other internal structures, besides plane parallel lamination, are sinusoidal ripple lamination (wavelength 2 to 6 inches, amplitude 0.5 to 1.5 inches), festoon trough cross-lamination (wavelength 2 to 3 inches,

Figure 25. De Courcy Tongue 2 on west side of Southey Bay. Thick sandstone beds in fore- and middle-ground show normal grading and locally, dish structures. Measured Section K-L, approximately interval 15 - 155 feet.

amplitude 1 inch), and one occurrence of sand waves with superimposed interference ripple marks (wavelength of sand waves 6 feet, amplitude 4 to 6 inches).

Near Southey Point, a two inch thick coal seam lies enclosed in bioturbated sandy mudstone. It covers about 3 square yards on a bedding plane although a few hundred pounds have been removed for domestic use (Winter, 1973). Beds in the lower part of the Southey Point member resemble those thick, graded beds of the Cedar District Formation which have thinly laminated and thinly platy to rippled or contorted tops. Eroded calcareous mudstone concretions up to 12 inches diameter occur suspended in a few sandstone beds. Other beds contain abundant clay matrix and contorted intraformational rip-ups.

Dish structures are locally well developed in the De Courcy sandstones. Immediately above the high-tide mark under a cavernous overhang at Southey Bay, dish structures exist in the middle of a normally graded bed. This cross-sectional view consists of horizontal alignments of gray, argillaceous, curved laminations which are disconnected and oriented convex-upward. Five feet laterally, outside of the cavernous overhang, the same bed appears structureless. Within the tidal zone on the west side of Southey Bay, a few etched beds contain small dishes developed subparallel to the bedding plane (Figure 26). The dishes can be broken out as separate entities,

Figure 26. Dish structures developed in Kd_2 on west side of Southey Bay. View is parallel to bedding. The structure has been emphasized as a result of preferential weathering of argillaceous partings which separate sandstone "dishes."

overlap, have convex lower surfaces marked by argillaceous films, and are about 1 to 3 inches diameter and 0.25 to 0.5 inches thick. The structure is intermittently developed along the bed and replaced laterally within five feet by an anastomosing etched surface which does not break down into plates. Dish structures are common in graded beds of Kd_2 on the east shore of Southey Bay and possible dish structures were observed in Kd_3 at Stone Cutters Bay.

Processes of Deposition

De Courcy sandstones were deposited by unidirectional currents and fluidized sediment flows which had some erosional capacity and dragged or bounced large objects along the bottom. Internal structures prove that at least some of the beds are the result of multiple events. Currents were at times confined or concentrated in small discrete channels (conglomerate channels and trough cross-beds). Deposition was from both bed traction (cross-bedding, festoon trough cross-lamination, parting lineation, pebbly sandstone, sand waves and conglomerate channels) and suspension (micaceous mudstone, micaceous laminae, sinusoidal ripple lamination (Jopling and Walker, 1968)). Interlamination of coarse and fine sandstone is indicative of velocity fluctuations. The generally low degree of sorting, winnowing, and rounding is indicative of rapid deposition and burial and lack of extended exposure to strong wave and current attack.

Dish structure forms during dewatering of rapidly deposited, underconsolidated, or quick beds but cannot be used to directly infer transportational or depositional processes (Lowe and LoPicollo, 1974). However, its occurrence at Southey Point in association with graded beds and beds with large dispersed and contorted clasts suggests deposition from fluidized sediment flows and/or proximal turbidites as envisioned by Middleton and Hampton (1973).

Depositional Environment

The De Courcy Formation of nearby Thetis and Kuper Islands is considered to have been deposited as marine and fluvial-marine sands in a delta-front environment (Simmons, 1973). In contrast to the Cedar District Formation, De Courcy sandstone bodies represent a more landward facies of a prograded clastic wedge. Because in surrounding areas the De Courcy is much thicker and composed of only one or two major bodies, De Courcy tongues of Saltspring Island are regarded as probably the relatively distal extensions of the main body of the formation. The De Courcy Formation is 1,400 feet thick to the northwest in Woodley Range (Rinne, 1973), perhaps more than 2,000 feet thick on North Pender Island to the southeast (Hudson, 1974), and about 800 feet thick on Saturna Island, farther southeast (Sturdavant, 1975).

Several factors suggest deltaic deposition: the De Courcy intertongues with marine mudstone and at least some of the sandstones are of marine origin (rare glauconite and Inoceramus, widespread burrows); sandstones are laterally extensive and were deposited at least partially by tractive processes; they were deposited by unidirectional currents which flowed to the northwest and west and show a low statistical variance (Figure 61); sedimentary textures and composition are similar to sediments of modern deltas. However, particularly suggestive of deltaic sedimentation is the occurrence of De Courcy sandstones conformably and gradationally overlying offshore marine facies of the Cedar District Formation and thereby forming upward-coarsening sequences.

The intertonguing Cedar District and De Courcy Formations form several upward-coarsening cycles of sedimentation which are well exposed on the north shore of Booth Bay, at Southey Point, and at Dock Point. Each upward-coarsening interval is interpreted as an offlap sequence which reflects seaward migration of depositional environments and a consequent shallowing and progression from low to higher energy processes with time and basin-filling (Visher, 1965).

Upward coarsening within the De Courcy Formation has been widely reported (Rinne, 1973; Simmons, 1973; Hudson, 1974) but was first related to progradation by Simmons. De Courcy Tongue 3, at Dock Point, is characterized in the lower part by thick-bedded, sole-marked sandstones with siltstone and mudstone interbeds; upward, sandstone beds become thicker and coarser, contain conglomerate channels, and are interbedded with siltstone and fine-grained sandstone. Scour-and-fill and cross-bedding also occur in the upper part. The key to interpretation of these upward-coarsening sequences is found in certain recent deltaic sediments. Many deltas show a decreasing grain size with increasing depth and a concentric basinward distribution of sand, interbedded sand-mud, and mud facies (Allen, 1967). Progradation results in stratigraphic offlap and records a gradational prodelta mud to delta-front interbedded and sand transition. Such regressive sequences are common to modern deltaic systems including the Fraser (Mathews and Shepard, 1962; Terzaghi, 1962), Mississippi (Scruton, 1960), Niger (Allen, 1970), and Rhone (Oomkens, 1967).

De Courcy sandstone bodies are considered to be sheet sands deposited on the inner delta-front slope, possibly at the mouths of active distributaries. As an analogue, bay-filling sequences of the Rhone River Delta are topped by a thick sheet sand. Progradational sequences of the Rhone Delta range from 30 to 220 feet thick and display the following vertical sequence:

5) sand with channel scour and cross-bedding;

4) horizontally bedded sand;

3) interbedded sand, silt, and clay showing an upward increase in cross-lamination and thickness of silt and sand beds;

2) clay with relict silt laminae and soft sediment deformation;

1) burrowed clays (Oomkens, 1967).

Other aspects of De Courcy sandstones are also compatible with delta-front sedimentation. For example, river mouth bars of the Niger Delta are composed of laminated fine- to medium-grained sands in which large-scale cross-bedding and cut-and-fill are uncommon. Well sorted very fine-grained sand and coarse silt occur in slightly deeper water (Allen, 1970). Fluvial-marine channel sands of the Fraser Delta are fine- to medium-grained, locally pebbly, and contain rounded silt clasts and calcareous sandstone concretions. Channel mouths are underlain by medium- to fine-grained sand whereas the remainder of the subtidal inner delta-front consists of laminated sand with silt and clay partings and minor crossbeds and current ripples (Johnston, 1921; 1922).

Graded De Courcy beds such as those at Southey Point which contain dish structures indicate deposition by slumping along a steep delta-front. See <u>Cedar District Formation Processes of Deposition</u>, and <u>Discussion of Depositional System.</u>

Northumberland Formation

Northumberland Formation originally denoted that rock-stratigraphic unit, exposed along Northumberland Channel in the Nanaimo area, which overlies the De Courcy Formation and underlies the uppermost sandstone (Gabriola Formation) of the Nanaimo Group (Clapp, 1912). Later, the sequence was subdivided into three units and the name Northumberland was retained for only the lower mudstone formation (Muller and Jeletzky, 1970).

By virtue of its combination of uniform lithology and position in sequence, the Northumberland Formation is a distinctive stratigraphic unit in the thesis area. Unlike the Cedar District Formation, it is devoid of thick sandstone beds. The Northumberland Formation overlies tabular upper De Courcy Formation sandstones and underlies the conglomeratic Geoffrey Formation. No diagnostic zone fossils were collected. A single faunal collection was identified for the author:

> Age and correlation. The lot #WBH-91-72 only contains a few peculiar Inoceramus which do not resemble any North Pacific inocerami species the writer is familiar with and may be new to the science. The lot #WBH-91-72 can not be dated at the present beyond the indication of a general Upper Cretaceous age. (Jeletzky, 1973)

Areal Distribution and Thickness

The Northumberland Formation underlies narrow strike valleys on the north and south limbs of the Kulleet Syncline. A prominent valley extends from Welbury Bay to Duck Bay. To the north, the formation forms the shore of Trincomali Channel southeast of Walker Hook and extends to the area south of Stone Cutters Bay. Excellent exposures occur on the seacliffs and shore platform southeast of Walker Hook. In addition, the Northumberland Formation crops out on the east and west shores of St. Mary Lake, and intertongues with the lower Geoffrey Formation on the northwest coast at Parminter Point and south of Idol Island.

At Welbury Bay a thickness of 1090 feet was measured (Measured Section M-N). At Duck Bay an incomplete thickness of 479 feet was measured above De Courcy Tongue 3 (Measured Section I'-J). A complete thickness of the interval from the top of De Courcy Tongue 2 to the base of the Geoffrey Formation, which includes Kn_1, Kd_4, and the main body of the Northumberland Formation, may be about 830 feet.

On the northwest coast south of Stone Cutters Bay, the main body of the formation is estimated by pace and compass traverse to be 840 feet thick. This thickness does not include intervals of intertonguing with the over- and underlying formations. A few hundred feet of Northumberland Formation mudstone occur southeast of Walker Hook, but the lower contact lies offshore in Trincomali Channel.

Contact Relationships

Contacts between the Northumberland and De Courcy Formations are conformable and have been discussed previously under De Courcy Formation. The contact with the Geoffrey Formation is also conformable, but of variable character. Proceeding from southeast to northwest, the contact is first sharp and planar, then gradational and intercalated, and finally on the northwest coast the formations intertongue through an appreciable stratigraphic interval. At the head of Welbury Bay, the contact is sharp, and except for load casts to 24 inches diameter and 10 inches relief, is planar. Very thick-bedded Geoffrey sandstone rests directly upon sandy mudstone of the Northumberland Formation.

In road cuts on the northeast side St. Mary Lake (South Bank Drive, Lot 13, Range 1 East) and Sunset Drive (0.5 miles east of Dock Point) the contact is gradational over a few tens of feet (Figure 27). At the latter locality, about 25 feet of thinly interbedded mudstone and sandstone (6 to 24 inches thick) intervene between the underlying silty mudstone and overlying 20-foot sandstone bed of the basal Geoffrey Formation. Sandstones comprise about 50 percent of the intercalated zones. They are very coarse- to fine-grained, poorly sorted, structureless, contain mud rip ups, and have sharp lower surfaces and gradational upper contacts.

The serrated shoreline between Parminter Point and Idol Island is a geomorphic expression of intertonguing. In vertical profile, intertonguing consists of resistant, very thick-bedded Geoffrey Formation sandstones and conglomerates which alternate with less resistant, finer-grained and more thinly bedded Northumberland (and Spray) Formation tongues.

Lithology and Stratification

The Northumberland Formation is composed predominantly of mudstone with lesser siltstone and minor sandstone. It closely resembles mudstone-dominated parts of the Cedar District Formation (mudstone facies).

Mudstone is medium dark gray (N4) to medium light gray (N6), fresh and weathered, and constitutes perhaps 80 percent of the formation. It has a tendency to initially break down into plates, but eventually weathers into chips with dimensions less than 0.5 inches. Mudstone occurs as laminae to thick beds and locally contains an appreciable silt admixture, minute mica flakes, and organic burrows. Fresh samples show very thin silty and micaceous laminae. Micritic mudstone concretions and lenses, similar to those of the Cedar District Formation, are common.

Siltstones and sandstones occur as rhythmically intercalated laminae to thin beds (rarely greater than 3 inches thick) which tend to weather out in relief and create weakly ribbed shore platforms. Color is medium gray (N5), plae brown (5YR 5/2) and light olive gray (5Y 6/1) weathered, and light gray (N7) fresh. Siltstones and sandstones vary from lenticular laminae less than 0.25 by 10 inches, to laterally persistent beds up to 14 inches thick. They have sharp and planar or loaded lower surfaces, and gradational to gently undulating upper contacts. Some beds are visibly graded from coarse to fine. Very thin lamination or cross-lamination is characteristic. Foresets of cross-lamination are invariably inclined to the northwest or northeast. Also, cross-lamination was seen to pass vertically into sinusoidal ripple lamination (wavelength 1 inch, aplitude 0.13 inches). Many cross-laminated siltstones pinch and swell along strike, others consist of a series of thin lenses on a bedding plane. A gently rippled bedding plane is well exposed along Scott Road. The ripples are "hummocky" with rounded crests and troughs.

The basal Northumberland Formation, consists of thinly-interbedded sandstone-siltstone-mudstone comparable to the "platy facies" discussed under <u>Cedar District Formation</u>, <u>Lithology</u>. Sandstones are fine- to very fine-grained, moderately to well sorted, laminated to thinly laminated and have an imperfect platy parting. Sinusoidal ripple lamination and contorted lamination, with folds overturned to the northwest, also occur.

At the head of Welbury Bay, the uppermost Northumberland Formation is very sandy and carbonaceous (Measured Section M-N). It contains poorly sorted coarse-grained sandstone lenses and much carbonized plant debris including wood with Teredo borings. In detail, silty mudstone contains large mica flakes and is interlaminated with poorly sorted coarse-grained sandstone lenses as minute as one inch wide.

Whereas megafaunal remains are rare in the Northumberland Formation, trace fossils are common. Megafossils include a large and probably new species of Inoceramus (Jeletzky, 1973), a single large ammonite - perhaps Pachydiscus (Usher, 1952), a single echinoid, and a few scaphopods and crushed immature Baculites.

Trace fossils occur widely as burrows, fecal pellets and mottled sediment. Locally they are so abundant that they destroy the continuity of interbedded siltstones and sandstones. Trace fossils are best preserved in freshly excavated material (such as the road cuts along South Bank Drive) and indurated rock of shore platforms (such as southeast of Walker Hook). The occurrence of Teredo borings in wood has been mentioned previously. At least three other types of traces are common:

1) light colored branching and meandering horizontal silt- and sand-filled tubes about 0.13 inches diameter are common on bedding planes. They also occur in a vertical

orientation but meander only in a horizontal plane coincident with siltstone or sandstone laminae;

2) Helminthoida (Chamberlain, written communication, 1975) is common as dark, clay-filled regularly meandering and looping tubes less than 0.13 inches in diameter. It is commonly seen as paired lenses or crescents.

3) Tomaculum problematicum (Chamberlain, written communication, 1975) occurs as strings of ovoid dark clay pellets. The pellets are about 0.03 to 0.05 inches in diameter and occur in both mudstone and siltstone.

Depositional Environment

The bulk of the Northumberland Formation was deposited in a low-energy normal marine setting occasionally subject to weak bottom currents. Molluscan faunas indicate a connection with the Pacific Ocean (Muller and Jeletzky, 1967). The abundant trace fossils suggest an oxygenated environment with open marine circulation (Chamberlain, 1971).

The trace fossils Helminthoida and Tomaculum are regarded as indicators of "moderately deep" water and compatible with a prodelta depositional environment at upper bathyal water depths (Chamberlain, 1975). However, Helminthoida also occurs in abyssal (greater than 6,000 feet) deposits and both Helminthoida and Tomaculum can occur in quiet shallow water sediments. Helminthoida is primarily a deep-water form recognized mainly in flysch sequences and in a few Deep Sea Drilling Project cores. Tomaculum has been identified mainly from deep-water deposits of the Ordovician (Chamberlain, 1975). Foraminifera and associated microfossils collected 70 miles northwest on Hornby Island are indicative of bathyal water depths of 1,000 to 1,300 feet (Sliter, 1973).

The lithology, sedimentary structures, and fossils are compatible with deposition in outer delta-front to prodelta environments comparable to those postulated for much of the middle and lower Cedar District Formation. Unlike the Cedar District Formation, there is little evidence of gravity depositional distal turbidites of siltstone and very fine-grained sandstone. Chaotic and prolapsed beds, pebbly mudstones, and proximal turbides are lacking.

The dominantly mudstone lithology with abundant organic burrows and rhythmic intercalations of siltstone and fine-grained sandstone is remarkably similar to modern prodelta sediments described by Allen (1970) and others (Table 3). Presumably, quiet water conditions prevailed and allowed clay, silt, and fine mica to settle slowly from suspension. A low sedimentation rate is also suggested by the intensity of organic burrowing. Feeble current action is recorded by sandstone-siltstone laminae and rippled bedding. It is possible that graded laminae are deposits of distal or low flow-regime density currents. Many contain incomplete Bouma sequences consisting of CDE (cross-lamination, parallel lamination, pelitic interval) and DE divisions.

Weak and intermittent tractive currents are well documented in the upper Northumberland Formation on the east side of St. Mary Lake (road cut along North End Road, Lot 12) where broadly lenticular siltstones are interbedded with mud-stone. The siltstones are 0.5 to 2.5 inches thick, a few hundreds of feet wide, and moderately to well sorted. They are composed of uniformly inclined and directed cross-laminae and readily part along foreset planes at regular 4- to 6-inch intervals. Partings reveal straight and parallel crests and slip face zones which merge tangentially with lower bedding planes. The siltstones are interpreted to be straight-crested micro-bars formed by northeast-flowing bottom currents. Periodic renewal of current activity and bedform advance is indicated by the regularity of partings which may occur at positions of clay-drape deposited between episodes of maximum current activity. The sorting and lenticular nature of beds can be ascribed to a paucity of available sediment and derivation of silt by winnowing of silty mudstone or reworking of a pre-existing silt layer.

Sandy and carbonaceous laminated mudstones of the uppermost Northumberland Formation at the head of Welbury Bay record a different marine depositional environment than the bulk of the formation. The interlamination of mudstone and lenticular poorly sorted coarse-grained sandstone depicts a low-energy environment subject to rapid velocity fluctuations of restricted areal extent. These physical characteristics in combination with abundant carbonized plant material are consistent with deposition in a shallow bay or protected tidal flat.

Geoffrey Formation

The name Geoffrey Formation was first applied to a middle sandstone and conglomerate subdivision of Clapp's (1914) original Northumberland Formation. Muller and Jeletzky (1970) extended the name Geoffrey to lithologically and stratigraphically similar, and apparently coeval rocks of the Nanaimo Basin.

A few *Inoceramus* fragments, but no diagnostic zone fossils, were found in the Geoffrey Formation.

Areal Distribution and Thickness

The Geoffrey Formation is preserved in a northwest-trending belt 0.5 to 1.0 miles wide and 9 miles long which straddles the axis of the Kulleet Syncline. On the east side of Saltspring Island it forms Scott Point, Athol Peninsula and the sheer cliffs bordering Trincomali Channel on the east side of Athol Peninsula. To the west, it forms a prominent cuesta scarp and dip slope extending northwest from St.

Figure 27. Geoffrey Northumberland Formation intercalated contact on the northeast side of St. Mary Lake (South Bank Drive). Note hammer at center for scale.

Mary Lake to Stuart Channel. On the northwest coast, the Geoffrey Formation forms Parminter Point and the serrated shoreline to the north of Parminter Point.

The thickness of the Geoffrey Formation on Saltspring Island is imperfectly known, but probably is between 600 and 900 feet. The thickness at Parminter Point is at least 600 feet (Measured Section O-P) and probably somewhat greater because the lower contact is covered by water, and the main body of the overlying Spray Formation and perhaps an undetermined thickness of Geoffrey Formation have been removed by erosion. From constructed cross-sections, the thickness on the west side of St. Mary Lake is roughly 850 feet. On the east side of St. Mary Lake, only an estimated 400 feet of section exists. The total thickness at Long Harbor is probably little more than 600 feet.

Contact Relationships

The lower contact with the Northumberland Formation is conformable and has been described previously. The upper contact with the Spray Formation is conformable, abruptly gradational and comparable to several contacts between major sandstone bodies and overlying mudstone formations that have been described previously. The upper contact of the Geoffrey Formation is best exposed on the northeast shore of Long Harbor, 0.4 miles north of the ferry landing, where a sequence of thinly interbedded siltstones, silty mudstones, and very fine- to fine-grained sandstones of the Spray Formation, overlies thick-bedded medium-grained sandstones of the uppermost Geoffrey Formation. The Geoffrey sandstone forms a low seacliff and the interbedded Spray sequence forms a broad intertidal shore platform.

Lithology and Stratification

The Geoffrey Formation is composed of sandstone and conglomerate and minor mudstone and siltstone. It is divisible into a lower sandstone member, a middle conglomerate and sandstone member, and an upper sandstone member, but also shows rather marked lateral variation (Figure 28):

1) conglomerates thin and bifurcate to the northwest and maximum clast size diminishes;
2) in the southeast at Nose Point, the upper sandstone member is conglomeratic; but to the northwest conglomerate is lacking;
3) on the northwest coast the Geoffrey Formation contains five Northumberland-Spray Formation tongues; to the southeast it contains only one (Spray Formation) tongue.

Lower Sandstone Member. The lower sandstone member is about 300 feet thick near the ferry landing at Long Harbor and of a

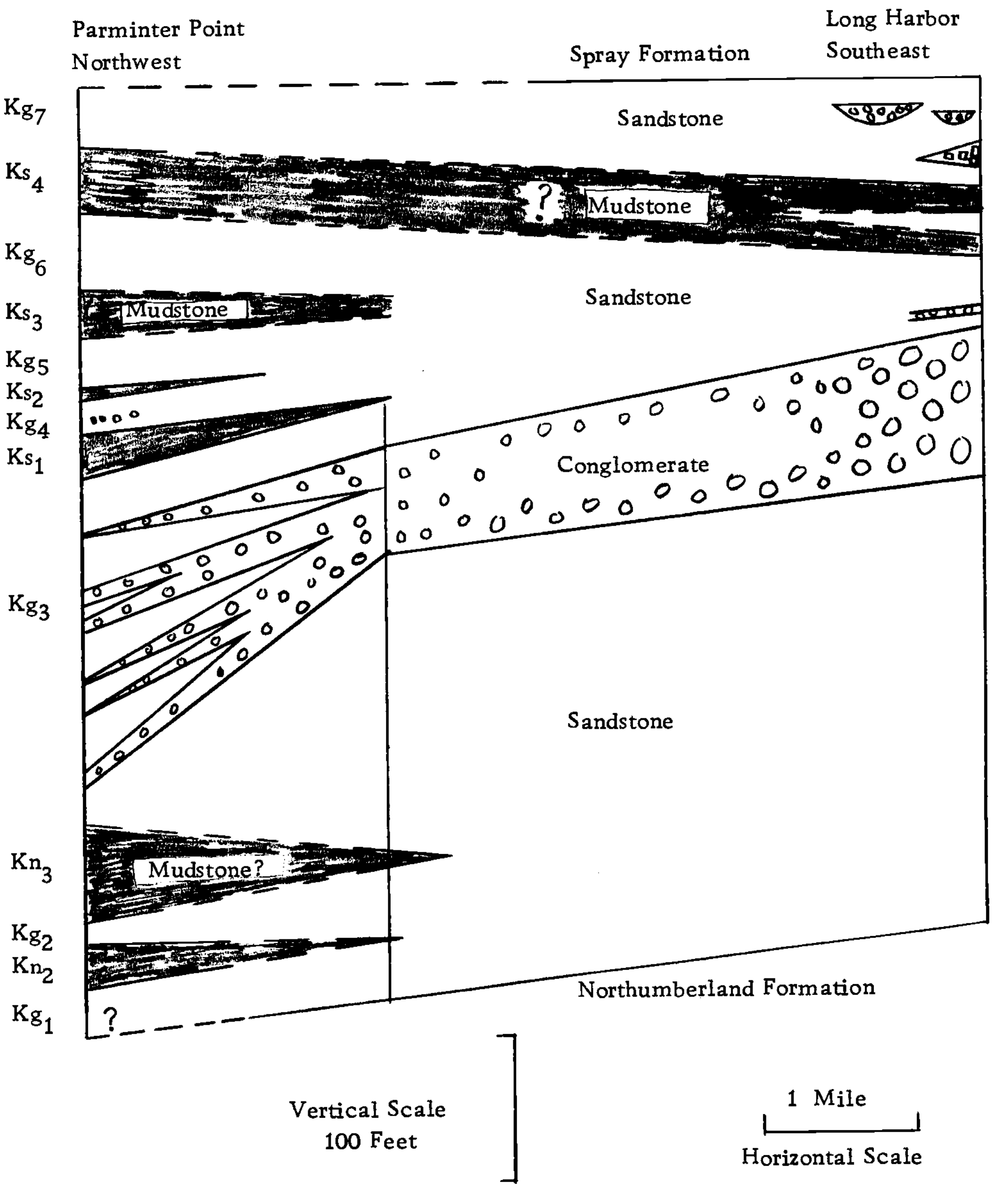


Figure 28. Geoffrey Formation stratigraphic relationships.

similar thickness along South Bank Drive on the east side of St. Mary Lake. A thickness of only 140 feet, which includes two Northumberland Formation tongues, occurs at Parminter Point although the base is covered by water.

Sandstones are thin- to very thick-bedded, attain at least 40 feet thick, and are predominantly very thick-bedded (greater than 4 feet thick). They are separated by thin, nonresistant interbeds. Weathered color of sandstones is yellowish gray (5Y 7/2) to light olive gray (5Y 6/1). Some beds showed a mottled weathered coloration. Fresh color is medium gray (N5) to medium light gray (N6). Sandstone beds are generally parallel-sided in outcrop although lensing is observable near the ferry landing at Long Harbor (Figure 29) and broad lenticularity on a scale of hundreds of a few thousands of feet is visible in the cliffs on the west side of St. Mary Lake. Lower contacts are sharp and commonly planar; but load casts, flute casts, flame structures and channeling occur. Upper contacts are sharp and planar, gently undulating, or gradational into the overlying interbed of siltstone or mudstone.

Sandstones are fine- to very coarse-grained, moderately to poorly sorted, and contain abundant intergranular matrix. Matrix-supported very fine to fine, subangular to rounded pebbles of quartz and dark chert are common. Sandstone grains are angular to

Figure 29. Very thick-bedded sandstones of the Geoffrey Formation lower sandstone member. Note channeling and hammer (arrow) for scale. Long Harbor ferry landing.

subangular and composed of quartz, feldspar, rock fragments, biotite and muscovite.

Indistinct plane parallel lamination is the most common structure in Geoffrey sandstones, but many beds are structureless. A blocky to slabby splitting property and primary current lineation also occur. Angular to rounded intraformational clasts of mudstone, siltstone and thinly laminated very fine-grained sandstone are locally abundant and usually less than 12 inches long. Also common are spherical calcareous sandstone concretions up to several feet in diameter. The concretions tend to be concentrated in thin stratigraphic intervals and differ from the enclosing sandstone only in their greater resistance to weathering and carbonate cement.

The thick Geoffrey sandstones are separated by partings or thin beds of mudstone, siltstone, and sandstone. Silty mudstone, siltstone, and very fine-grained thinly laminated or cross-bedded sandstone are most common. Rare interbeds of reddish-weathering, muddy, medium- to coarse-grained sandstone with abundant carbonized plant fragments occur. An interbed near the top of the lower member at Long Harbor consists of bioturbated silty mudstone with abraded Inoceramus valves.

Middle Conglomeratic Member. The middle member of the Geoffrey Formation is composed of conglomerate, sandstone, pebbly sandstone, and rare mudstone. On the northeast shore of Welbury

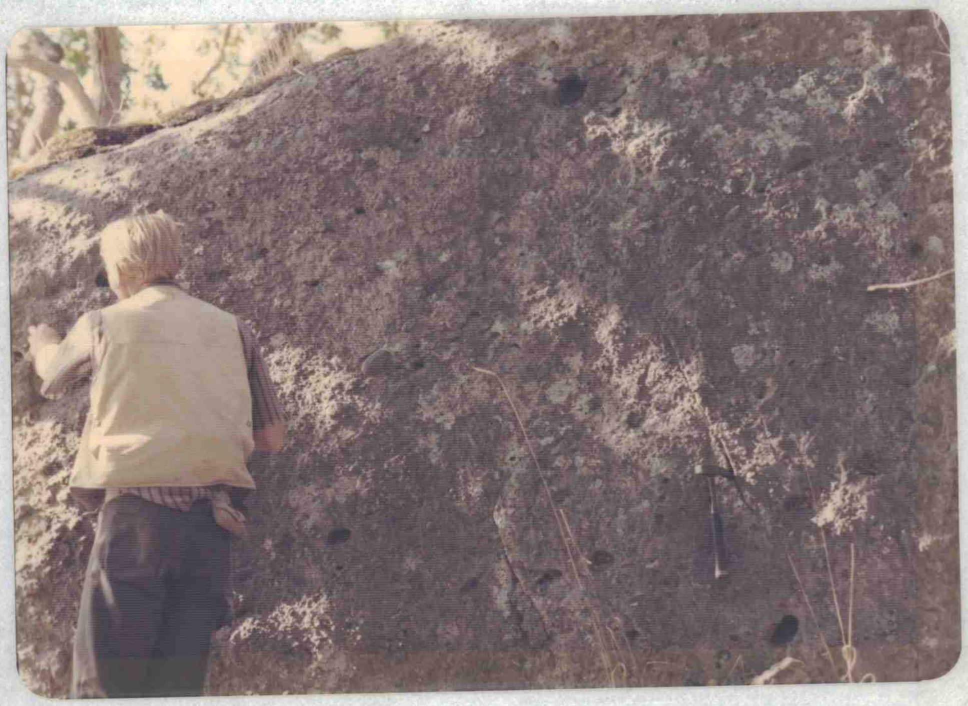


Figure 30. Geoffrey Formation fluvial conglomerate. Note imbrication of coarse pebbles and cobbles, current flowed to the right (north). Channel in upper member near Nose Point.

Bay, it consists of a vertically continuous pebble to boulder conglomerate sequence 90 feet thick. Also present are thin sandstone lenses. Farther northwest, the member is composed of coarse sandstone with numerous well sorted pebble conglomerate bands and lenses and a few thick, laterally continuous conglomerate beds. The middle member is 234 feet thick at Parminter Point (Measured Section O-P). Overall, there is a pronounced southeast to northwest decrease in maximum clast size (Figure 31).

Weathered conglomerate is olive gray (5Y 5/1) to light olive gray (5Y 6/1) in color. In the southeast it is indistinctly very thick-bedded and composed of clasts up to 26 inches in length. At Parminter Point and along Sunset Drive, fine to coarse pebbles predominate. Clasts are tightly packed, mostly subrounded to well rounded, contain a sandstone matrix, and are composed of porphyritic, intermediate, and silicic volcanics with lesser amounts of chert, argillite, phyllite, quartzite, schist, granitics, diorite, mudstone, and sandstone. Imbrication is uncommon. Conglomerate commonly backfills channels cut into underlying sandstone (locally 3 feet of relief over 6 to 10 feet of contact). A few Inoceramus shell fragments were found in pebble conglomerate 0.5 miles north of Parminter Point on Sunset Drive.

Upper Sandstone Member. The upper sandstone member of the Geoffrey Formation consists of sandstone conglomerate and mudstone.

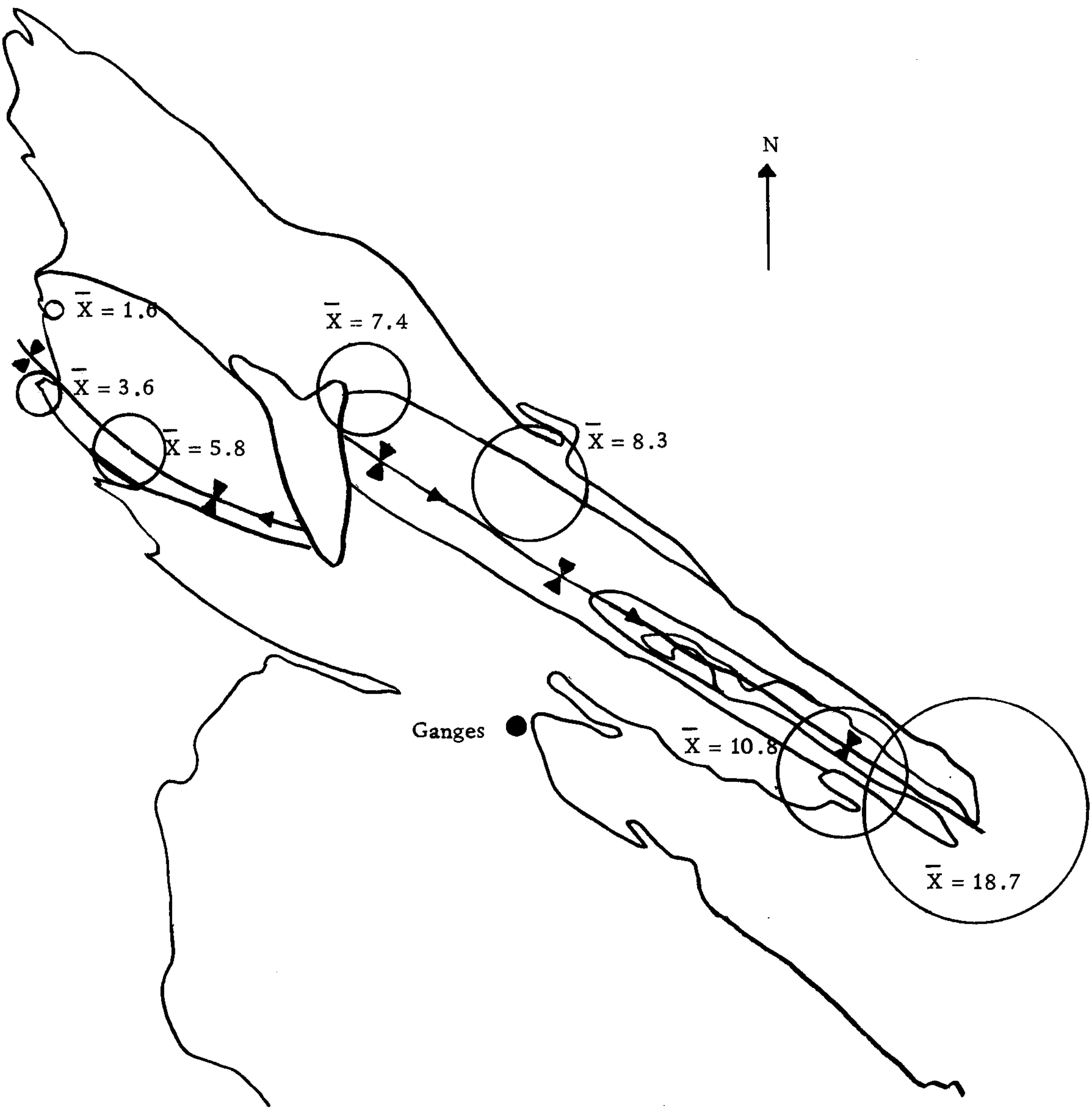


Figure 31. Means of the diameters of the five largest conglomerate clasts at outcrops of the Geoffrey Formation middle member. Diameters are in inches.

At Nose Point it is estimated to be less than 200 feet thick and contains a single Spray Formation tongue. At Parminter Point, the upper sandstone member is at least 260 feet thick and contains 4 Spray Formation tongues.

Sandstones of the upper member are similar in texture, composition and stratification to those of the lower member; they are medium- to coarse-grained, moderately to poorly sorted, and very thick-bedded. The sequence at Nose Point contains scour-and-fill, lamination and small pebble conglomerate channels (about 6 feet wide and 6 inches deep). A larger pebbly sandstone and conglomerate channel- at least 100 feet wide and 10 feet deep- contains imbricated pebbles and cobbles (Figure 30). Imbrication of clasts and the trend and plunge of channel and clast axes record sediment transport to the north northeast. Also at Nose Point is an intraformational breccia 30 feet thick which is composed of randomly oriented, angular mudstone clasts up to several feet diameter (Figure 32). Some of the clasts contain iron sulfide and micritic mudstone concretions. The breccia is apparently a lenticular body and not present along the shoreline laterally to the southeast, a distance of about 1,000 feet.

Depositional Environments

The Geoffrey Formation was deposited in marine and fluvial or fluvial-marine environments. The association, sequence, and

Figure 32. Intraformational breccia in upper Geoffrey Formation near Nose Point. Stratification in surrounding units dips steeply to the right.

geometry of lithofacies are suggestive of a northerly progradation of depositional environments. The degree of compositional immaturity suggests that the sediment was derived from a local source of high relief and was rapidly delivered to the depositional site by high-gradient streams. The conglomerates are regarded to be of fluvial and shallow marine origin. Features interpreted as fluvial include local imbrication, channeling, tight packing, and great lateral extent. Well sorted and rounded pebble conglomerates west of St. Mary Lake may have been deposited as beach gravels; deposition in a marine environment is indicated by the occurrence of *Inoceramus* fragments at one locality. The low degree of sorting and abundant matrix in sandstones are compatible with their deposition in fluvial or marine delta-front environments.

The vertical sequence, offshore marine mudstone to fluvial conglomerates, and the apparently continuous nature of sedimentation, are indicative of progradation. The Northumberland-Geoffrey upward-coarsening cycle is comparable to fluviomarine offlap sequences of modern deltas. Such sequences result from outbuilding when the rate of sedimentation exceeds both basin subsidence and redistribution by marine waves and currents. However, eustatic lower of sealevel might also explain the observed superposition of facies. The rather great thickness of the Northumberland-Geoffrey cycle probably is a result of progradation into fairly deep water or/and persistent basin subsidence.

Lateral changes within the Geoffrey Formation middle and upper members show that the southeastern part of the study area was closer to the source or to the major channels and that current competence decreased to the northwest. The increased number of mudstone tongues to the northwest suggests that the main body of the Geoffrey Formation was deposited in the southeast or south.

Spray Formation

The name Spray was applied by Usher (1952) to the "shales" which overlie the Geoffrey Formation in the Comox Basin. The name was later extended to the Nanaimo Basin by Muller and Jeletzky (1970) who correlated the "upper shales" of Clapp's (1914) undivided Northumberland Formation with the Spray Formation of the Comox Basin.

Spray Formation is the stratigraphically highest unit in the thesis area. No megafossils were found.

Areal Distribution and Thickness

The main body of the Spray Formation underlies a narrow zone 3 miles long and less than 0.5 miles wide. It is preserved astride the axis of the Kulleet Syncline along the shoreline of Long Harbor and to the northwest at least as far as Mansell Road. In addition, thin Spray Formation tongues, 12 to 40 feet thick, occur at Parminter Point and Nose Point.

The thickness of the main body is estimated to be at least 400 feet. About 335 feet, estimated by pace and compass traverse, of Spray Formation occur on the north shore platform of Long Harbor, Lot 9.

Contact Relationships

The conformable and gradational contact with the underlying Geoffrey Formation is exposed 0.4 miles north of the Long Harbor ferry landing and has been described previously. See Geoffrey Formation, Contact Relationships.

Lithology and Stratification

The Spray Formation is lithologically similar to the Northumberland Formation except for a possibly higher silt content. The lower Spray Formation is comparable to the interbedded "platy facies" of the underlying mudstone formations. The basal 90 feet consist of thinly interbedded platy siltstone, silty mudstone, and fine- to very fine-grained sandstone. Sandstones are olive gray (5Y 4/1), weathered, and comprise about 20 percent of the basal 90 feet, of the formation. Sandstones are very thin- to thin-bedded

(1 to 6 inches thick), are internally thinly laminated (10/inch) with a platy splitting property, and contain calcium carbonate cement and limited sinusoidal ripple lamination. Weathered upper and lower contacts appear sharp and planar.

The upper part of the Spray Formation is well exposed at the northwest end of Long Harbor, and consists of silty mudstone with interlaminations of siltstone. Mudstone is light gray (N6) weathered, and medium gray (N4) fresh. It occurs in thin beds (0.5 to 2 inches thick) and has an imperfect platy splitting property, eventually weathering to small chips. Mudstone is noncalcareous but contains a few scattered dark gray ellipsoidal calcareous mudstone concretions a few inches in diameter. Also present is fine scale bioturbation and larger distinct trace fossils which consist of silt-filled tubes about 0.25 inches in diameter.

Rhythmically interbedded with mudstone are light gray (N7) siltstone laminae and lenticular laminae (0.5 inches and less thick). Siltstones are calcareous and comprise roughly one-third of the exposures. A few zones up to 6 feet thick of contorted and prolapsed bedding occur.

Spray Formation tongues consist of thinly interbedded mudstone, siltstone and sandstone. Sandstones are fine- to very fine-grained, thinly laminated (14/inch), cross-laminated, and locally contain festoon trough cross-lamination and recumbent soft-sediment folds. Cross-laminae indicate sediment transport to the northwest and to the east. Penecontemporaneous folds have amplitudes and wavelengths of about 2 inches and are overturned to the north. At Nose Point, a thick fine-grained sandstone shows multiple low-angle truncations and shallow trough cross-bed sets (about 6 inches deep and 10 feet wide) which record sediment transport to the north-north-east.

Depositional Environment

The Spray Formation was deposited in environments comparable to those postulated for similar parts of the Northumberland and Cedar District Formations. The thinly interbedded mudstone-siltstone facies records low energy offshore marine conditions such as might occur in delta-front or prodelta environments. Foraminifera from the Spray Formation on Hornby Island in the Comox Basin, 70 miles northwest of Saltspring Island, are indicative of bathyal water depths of 1,600 to 1,900 feet (Sliter, 1973).

The basal unit was deposited in a more agitated and probably shallower environment. Silty mudstone and siltstone interbeds from the basal 100 feet were examined for microfossils. The less than 80 micron (very fine silt and clay) fraction is dominated by land-derived spores and pollen; marine dinoflagellates are poorly represented. The assemblage records a depositional site close to shore, or close to major drainage systems carrying large amounts of non-marine palynomorphs (Leffingwell, 1974).

Discussion of Depositional System

The term delta as applied to the Nanaimo Group by this author is used in a comprehensive sense: the subaerial and submerged contiguous sediment mass deposited in a body of water primarily by a river (Moore and Asquith, 1971). Although many analogies with modern deltaic systems have been cited, Holocene deltas may not be typical of the geologic past; lowered Pleistocene sea level created a broad, flat shelf onto which deltas are now building.

Features of Nanaimo Group deltas not typical of many Holocene deltas include:

1) coarseness of the landward (proximal) facies, coarse sandstone and conglomerate;
2) a basinward (distal) facies with widespread turbidites;
3) comparatively small proportion of silt and clay, and a large proportion of sand and gravel in the landward facies;
4) A lack of abundant shallow marine bar sands.

Apparently Nanaimo Group deltas were characterized by rather high gradients and active distributaries which reached directly to the delta-front so that silt and clay were flushed offshore. High gradient fluvial systems are characterized by a scarcity of swamps, slackwater areas, and floodplain silt and clay (Selley, 1970). Also, a tectonically active source area would have been affected by rapid erosion and mainly mechanical weathering to yield coarse clastics rather than clay, a product of chemical weathering. The lack of abundant well sorted shallow marine bar sands could result from progradation into a fairly deep and sheltered low energy basin such as the modern Strait of Georgia. Progradation into deep water would also explain the widespread evidence of steep paleoslopes (turbidites, pebbly mudstone, chaotic beds and other products of slope-controlled transport mechanisms).

The Cedar District, De Courcy, Northumberland, and Geoffrey Formations resemble the fan delta depositional system more closely than classical deltas. Fan deltas are clastic wedges built into a standing body of water (Fisher and Brown, 1972). They are fed by a nearby uplifted source and, like deltas, develop a progradational sequence. Fan deltas or tectonic deltas are characterized by high gradients, a high proportion of coarse, commonly feldspathic sands and lithic gravels, show a distal size gradation caused by a loss of gradient, and tend to stack up in thick sequences (Erxleben, 1975). Where prograded across a narrow shelf, fan deltas can be associated with a coarse marine slope system characterized by proximal turbidites and slumps (Fisher and Brown, 1972). Pre-glacial continental margins may have had narrow shelves (Moore and Asquith,

1971) and might have favored development of a deltaic system with a continuous basinward gradation from fluvial to marine delta-front slope deposition.

A small fan delta is illustrated by Holmes (1965). Cretaceous clastics of central Oregon are similar to the Nanaimo Group, being characterized by a cyclicity of sedimentation, complex intertonguing of fluvial sandstone-conglomerate with marine mudstone, and a lack of longitudinal bar deposits. Deposition was as deltas or fans which entered a large sheltered marine basin (Wilkinson and Oles, 1968; Oles and Enlows, 1971).

PETROLOGY OF CRETACEOUS ROCKS

Sandstones

Seventy thin-sections of sandstones were examined with a petrographic microscope and 52 were classified according to the modal mineralogy determined by point-counting. A minimum of 400 points per section were identified utilizing a mechanical stage, 1 millimeter grid, and magnifications of 28, 80, and 320X.

Detailed petrologic descriptions are presented in Appendix II and collection localities are plotted on Figure 33. Four general classes of sandstone components - framework grains, matrix, cement, voids - are discussed below.

Framework Grains

Framework grains, sand-size particles, are allocated to six general categories: quartz, feldspar, rock fragments, micas, iron-bearing minerals, and others. The six categories are composed of 22 major species and detailed below. Individual mineral and rock fragment abundance is presented as a percentage of the total points counted per thin-section.

Quartz. Quartz is recognized as clear, colorless, unaltered grains which show the characteristic optical properties. Four species are recognized:

1) normal monocrystalline quartz (NQ) extinguishes within 5 degrees of rotation;
2) undulatory quartz (UQ) shows wavy extinction through a rotation of 5 degrees or more;
3) polycrystalline quartz (PQ) is composed of several grains which have distinct boundaries and different extinction orientation;
4) chert is a microcrystalline aggregate of relatively pure quartz; minute inclusions of pyrite, iron-oxide, and clay are common.

Quartz is a major component of Nanaimo Group sandstones and ranges in abundance from 10 to 44 percent. In general, normal quartz is most abundant, and polycrystalline quartz is least abundant. However, polycrystalline quartz, undulatory quartz, and chert are more abundant in the Comox (Figure 43) and Extension-Protection Formations than in the younger Cedar District, De Courcy, and Geoffrey Formations. Two distinct varieties of polycrystalline quartz are common to the Comox Formation:

1) probable vein quartz consists of aggregates of clear, equant grains with straight, simple contacts;
2) metamorphic polycrystalline quartz is composed of a mosaic of subparallel elongated grains with sutured (sawtooth) contacts. Inclusions of epidote and chlorite are common.

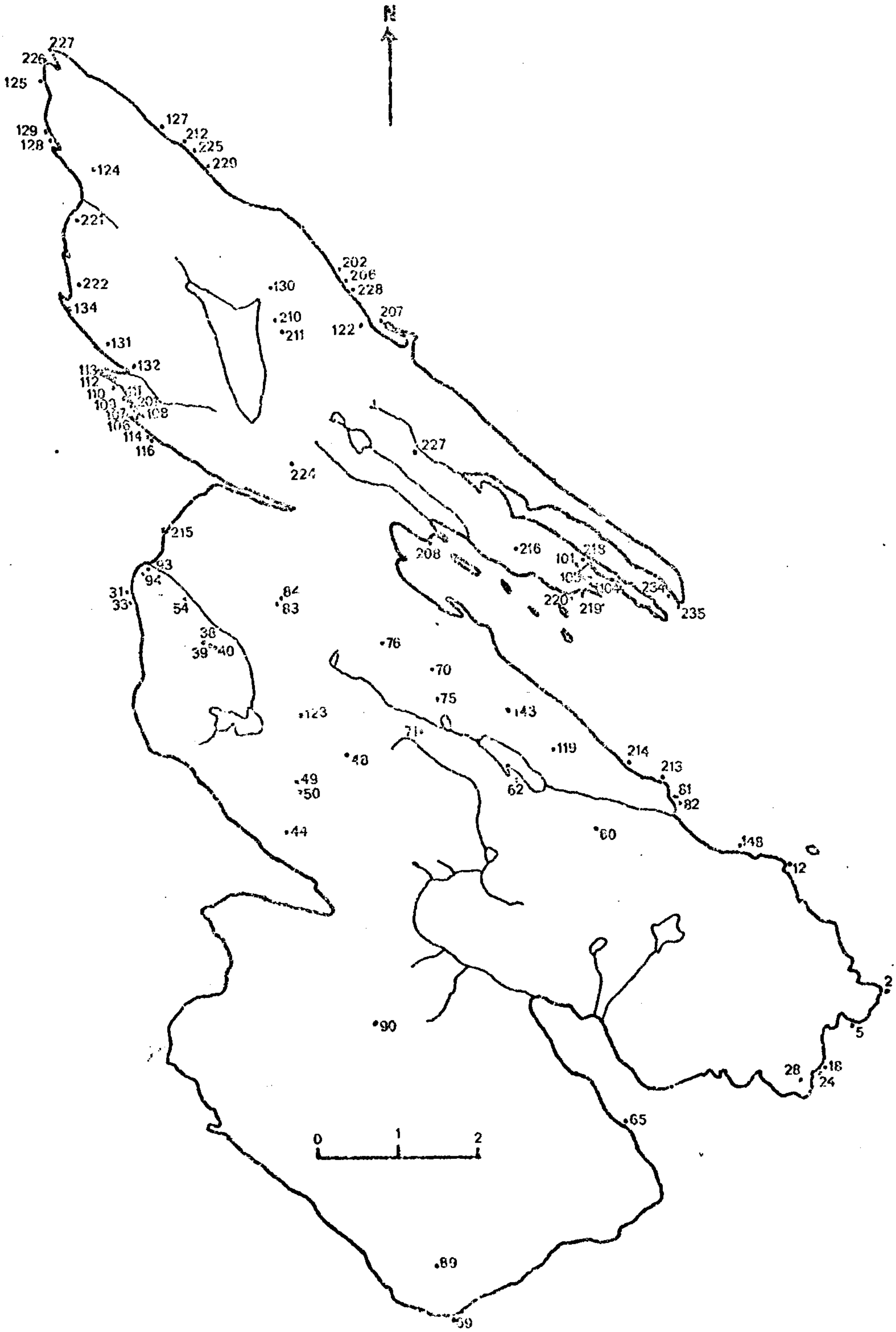


Figure 33. Locations of samples examined in thin-section.

Some of the chert grains possess a texture like that of so-called "radiolarian cherts" - clear circular patches (about 0.05 millimeters in diameter) of chalcedonic or slightly more coarsely crystalline quartz in a dusty microcrystalline quartz groundmass.

Feldspars. Feldspars are recognized by their characteristic optical properties, twinning, cleavage, and varying degrees of alteration to sericite and kaolinite or a cloudy character. Feldspars in the Cretaceous sandstones are divisible into four major categories:

1) plagioclase has one or more of the following properties: polysynthetic twinning, positive optical sign and large 2V, refractive index greater than quartz, zoning, preferential alteration to laumontite;
2) orthoclase has a negative optical sign, low to moderate 2V, refractive index less than quartz, and lacks alteration to laumontite;
3) microcline has quadrille structure (cross-hatch polysynthetic twinning) and/or spindle-shaped polysynthetic twins (Figures 34 and 38);
4) orthoclase-plagioclase undifferentiated.

In addition, the content of plagioclase and potassic feldspars was investigated by point-counting billets stained according to the methodology developed by Bailey and Stevens (1960). Billets were counted with a mechanical stage, 1 millimeter grid (400 points), reflected light and magnitications of 28 and 40X. Data are given in Appendix IV. High potassium feldspar counts, such as 20 percent for sample 223, are the result of including stained volcanic rock fragments which cannot be effectively differentiated from stained feldspar.

Feldspar in the Nanaimo Group sandstones is slightly less abundant than quartz and ranges from 14 to 44 percent. Plagioclase is most abundant (2 to 33 percent), generally untwinned, and slightly cloudy. However, polysynthetic twinning is common although zoning is rare. Some grains of plagioclase are largely replaced by laumontite (Figure 39). Such grains are counted as plagioclase whereas intergranular laumontite is regarded as a cement. Laumontite replaces only plagioclase (rarely quartz) and commonly exhibits a reticulate pattern.

Plagioclase is predominantly oligoclase and andesine. Maximum extinction angles obtained from numerous measurements on albite twins (Michel-Levy method) indicate a maximum of An 45-47 for the Cedar District, De Courcy, and Geoffrey Formations. Measurement of combined Albite-Carlsbad twins gives An 43. No significant differences in anorthite content of plagioclase in the Cedar District, De Courcy, and Geoffrey Formations were noted. A maximum of An 34 was determined for the Extension-Protection and Comox Formations. Feldspars in the Comox and Extension-Protection Formations

Figure 34. Photomicrograph of Comox Formation fluvial sandstone, arkosic arenite. Note tightly packed grains, microcline (M) and epidote (E). Crossed nicols. Width of field is four millimeters. Sample 62.

are rich in inclusions of chlorite, epidote, and sericite relative to feldspars in overlying formations.

Orthoclase grains are generally untwinned, larger, and less altered than plagioclase. Orthoclase content is very low in the Comox Formation (0-2 percent) and reaches a maximum of 11 percent (counted in thin-section) higher in the Nanaimo Group. Counts of stained billets also suggest a low content of potassium feldspar in the Comox Formation.

Microcline, although present in all formations, is rare in all sandstones except those from the upper member of the Comox Formation. Microcline reaches a maximum abundance of 5 percent in the Comox upper sandstone member and only trace amounts occur in all younger formations. Average abundance in the sandstones of the Comox upper member is 2.8 percent which is significantly different, at the 95 percent confidence level, from abundance in all other formations (Van Der Plas and Tobi, 1965).

Traces of sanidine and myrmekite occur in the De Courcy and Geoffrey Formations.

Rock Fragments. Rock fragments are a major component in sandstones of the Nanaimo Group. They are allocated to four categories: volcanic rock fragments (VRF), metamorphic rock fragments (MRF), intrusive igneous rock fragments (IRF), and undifferentiated rock fragments. Abundance of rock fragments ranges from 2 to 47 percent and is generally less in the fine-grained sandstones.

Several trends are recognized:

1) metamorphic rock fragments are abundant only in the Comox Formation (average 21 percent), particularly in the marine sandstones from Beaver Point and Yeo Point (43 percent). Metamorphic rock fragments are least abundant in the Cedar District and younger formations (1-7 percent) and of intermediate abundance in the Extension-Protection Formation (3-17 percent).

2) volcanic rock fragments become abundant in the De Courcy (1-11, average 4.5 percent) and especially Geoffrey Formations (2-25, average 9 percent) but are less abundant in the Comox and Extension-Protection Formations (0-4, average 1 percent);

3) intrusive igneous rock fragments show little variation throughout the stratigraphic section, but may be slightly more abundant in the Geoffrey than in other formations.

Several types of metamorphic rock fragments occur in the Comox Formation; schist, phyllite, and nonfoliated clasts of epidote-chlorite-plagioclase-sericite are most common. Schists are generally chloritic (greenschists) and contain muscovite, quartz and epidote; quartz biotite, quartz-muscovite, and quartz-actinolite schists are less common. Metamorphic rock fragments of the Extension-Protection

Formation are quite similar to those of the Comox Formation, but phyllitic chert, argillite, and greenstone (highly altered volcanic rock fragments) are also abundant. Graphitic phyllite, mica-schist, and argillite are the more common metamorphic rock fragments in overlying formations.

Volcanic rock fragments constitute five percent or more of many upper Cedar District, De Courcy, and Geoffrey Formation sandstones. Hyalopilitic and pilotaxitic textures in which the groundmass is devitrified or altered to a green, fibrous material, are common. Fragments of spherulites, consisting of radial aggregates of chalcedonic quartz (Figure 35) are common in the Geoffrey Formation. Volcanic rock fragments are commonly contorted and penetrated by adjacent grains. In carbonate-cemented concretions of the Geoffrey Formation, relatively fresh volcanic rock fragments of hornblende andesite and rhyolite mineralogy occur. Many show flow banding in a pale red-brown groundmass of glass or devitrified glass and contain phenocrysts of quartz, green hornblende laths, plagioclase, and sanidine. Volcanic rock fragments have contributed to the widespread diagenetic matrix; the green groundmass of some volcanic rock fragments is identical to and merges imperceptibly with pasty to fibrous intergranular matrix (Figure 36).

Intrusive igneous rock fragments are approximately granodiorite in composition; they consist of an intergrowth of coarsely crystalline

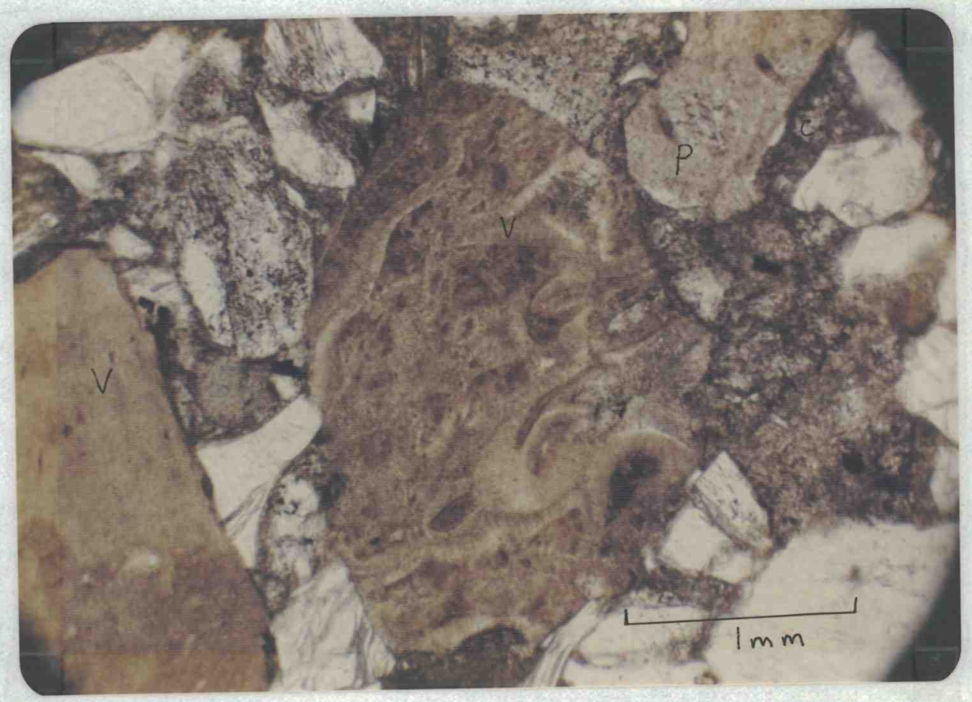


Figure 35. Photomicrograph of Geoffrey Formation lower sandstone member concretion. Note devitrified volcanic glass (V), euhedral plagioclase (P), and carbonate cement (C). Plane light. Sample 131, lithic arenite.

quartz, feldspar (plagioclase, orthoclase, microcline and perthite), and an accessory mineral such as biotite or muscovite. Probably a few coarsely crystalline metamorphic rock fragments, such as gneiss, were counted as intrusive igneous rock fragments. Intrusive igneous rock fragments of the Geoffrey Formation include unaltered clasts composed of muscovite-plagioclase-orthoclase, quartz-plagioclase-orthoclase, and quartz-feldspar-biotite-myrmekite.

Micas. Micas are a conspicuous but subordinant component of Nanaimo Group sandstones (trace - 15 percent). They occur as flakes up to several millimeters long, are commonly contorted by compaction and expanded by the growth of calcite, laumontite, and prehnite (Figure 41) between cleavage planes. Biotite (0-8, average 3 percent) is most abundant. Muscovite (0-3, average 1 percent) is more abundant than chlorite. However, chlorite flakes are particularly abundant (4-6 percent) in some of the Comox and Extension-Protection Formation sandstones.

Iron-bearing Minerals. This category of framework grains includes a few moderately abundant iron-bearing minerals other than biotite and chlorite. Epidote, hornblende, and magnetite are the most common species.

Epidote is the most common iron-bearing mineral and is present in all formations. It ranges in abundance from a trace to 11 percent and averages over 4 percent in the Comox Formation and less than l percent in all other formations. Epidote occurs as polycrystalline aggregates, euhedra, equant angular grains, and striated prismatic grains.

Hornblende is common in only the Comox (0-8 percent) and Geoffrey (0-5 percent) Formations and occurs only in trace amounts in the other formations. Both dark green and pale blue-green hornblende occur in the Comox Formation upper sandstone member as angular laths. Dark green angular hornblende laths occur as grains and as phenocrysts in volcanic rock fragments in the Geoffrey Formation.

Magnetite is an ubiquitous mineral, but is most abundant in the Geoffrey Formation average (0.5 percent). Black metallic minerals (mostly magnetite) comprise 71 percent of Comox sample 39 which is a beach placer.

Others. Other framework grains which are of very minor abundance are skeletal calcite, glauconite and apatite. Pelecypod fragments occur in two samples (2 and 129). A single multi-chambered Foraminifera test, resembling the planktonic form Globigerina, was noted in sample 110, a proximal turbidite sandstone from the upper Cedar District Formation. Glauconite pellets occur in one Cedar District and one De Courcy Formation sandstone. Apatite grains occur only in trace amounts in the Geoffrey Formation.

Voids

Pore spaces constitute an average of only 2 percent of the Nanaimo Group sandstones (range 0-13 percent). Seven thin-sections contain between 5 and 13 percent of intergranular void space. Average porosity values are highest in the De Courcy Formation (3 percent) and lowest in the Extension-Protection Formation (1 percent). Some voids are probably a result of plucking during preparation of the thin-sections and dissolution of carbonate cement during weathering of outcrops. Several factors have contributed to the low proportion of voids:

1) tight packing, interpenetration of grains, and sutured contacts;
2) poor sorting and angularity of grains, high clay matrix contents;
3) locally abundant diagenetic clay matrix in the coarse-sandstones;
4) a variety of cements.

For further discussion of factors affecting porosity, see Matrix, Cement, and Textural Aspects, below.

Matrix

Intergranular clastic material with dimensions of less than 0.05 millimeters was classified as matrix. Gilbert (Williams, Turner, and Gilbert, 1954) considers matrix to be clay- and fine silt-size fragments.

Two types of matrix occur in Nanaimo Group sandstones: detrital and diagenetic. Detrital matrix consists of clay- and silt-size fragments of minerals, rocks, and organic matter which were deposited more or less concurrently with the surrounding framework grains. Diagenetic matrix consists of material formed post-depositionally at, presumably, low temperatures within the sedimentary deposit (Williams, Turner, and Gilbert, 1954).

Detrital matrix consists of poorly sorted, generally brown, intergranular material with distinct silt-size angular grains of quartz, feldspar and micas. In contrast, diagenetic matrix is generally olive green paste which contains minute, equant, opaque inclusions. Diagenetic matrix also fills intergranular pores and appears amorphous or possesses a low to moderate birefringence which is largely masked by the color. At high magnification, the diagenetic matrix appears to be a felted aggregate of slightly pleochroic microcrystalline fibers. There is abundant petrographic evidence that the pasty green matrix was formed by post-depositional alteration of the hyaline or devitrified groundmass of fine-grained volcanic rock fragments; appearance of abundant diagenetic matrix coincides with the first occurrence of abundant volcanic rock fragments in the stratigraphic section (upper Cedar District Formation). All stages of transitions exist from "fresh," translucent, flow-banded hyalopilitic volcanic rock fragments, similar rock fragments with green alteration surrounding plagioclase and hornblende phenocrysts, and finally to green clay matrix filling minute intergranular cracks and pores (Figure 36). Diagenetic matrix most closely resembles a mica and is similar to celadonite, commonly an alteration product of volcanic glass. Optical properties of the matrix include weak pleochroism, usually parallel extinction, and a biaxial positive interference figure with a small 2V.

Both detrital matrix and diagenetic matrix are widespread. Detrital matrix is common in Extension-Protection Formation fluvial sandstones (samples 70 and 82 contains 6 percent), in some Comox Formation fluvial sandstones (samples 71 and 44), and is particularly abundant in pebbly mudstones (sample 127 contains 60 percent matrix and dispersed texture) and some of the thick, graded proximal turbidite beds of the Cedar District and De Courcy Formations (samples 109, 110, 122, 212, 220, 226 contain 11 to 20 percent matrix). Diagenetic matrix is most prevalent in the coarse Geoffrey Formation sandstones (up to 17 percent) but does not occur in the carbonate-cemented concretions (Figure 37). Because of the abundance of diagenetic matrix in many samples, it is often difficult to evaluate the content of detrital matrix. In most cases where matrix is abundant, a significant proportion is diagenetic in origin and the

Figure 36. Photomicrograph of Geoffrey Formation arkosic wacke from base of lower sandstone member. Note porphyritic volcanic rock fragment and its altered groundmass (M) which grades into intergranular diagenetic matrix. Crossed nicols. Sample 132.

sandstones may have contained little matrix when deposited. Average total matrix values are: Comox Formation 1.3 percent; Extension-Protection Formation 4.6 percent; Cedar District Formation 13.6 percent; De Courcy Formation 7.8 percent; Geoffrey Formation 9.2 percent.

Cements

Seven types of pore-filling cements occur in the sandstones: calcite, laumontite, quartz, iron-oxide, pyrite, feldspar, and an unidentified fibrous green mineral which resembles chlorite; only calcite, laumontite, quartz, and iron-oxide are common. Prehnite is abundant in two samples from the Comox Formation, and, although it does not fulfill the textural criteria (pore-filling) of a cement, it is discussed in this section. Diagenetic matrix probably acts as an effective bonding agent, and thus could also be considered a cement.

Calcite. Calcite occurs in sandstones of all 5 of the formations which were sampled and ranges from 0 to 37 percent. It occurs as pore-filling and fracture-lining sparry calcite and as microcrystalline carbonate disseminated throughout matrix material. Calcite commonly replaces framework grains (Figure 37) creating embayed and serrated grain margins (Figure 50), cement-supported textures, and pseudomorphs after hornblende and twinned plagioclase. In some sandstones of the Geoffrey Formation, the groundmass of volcanic

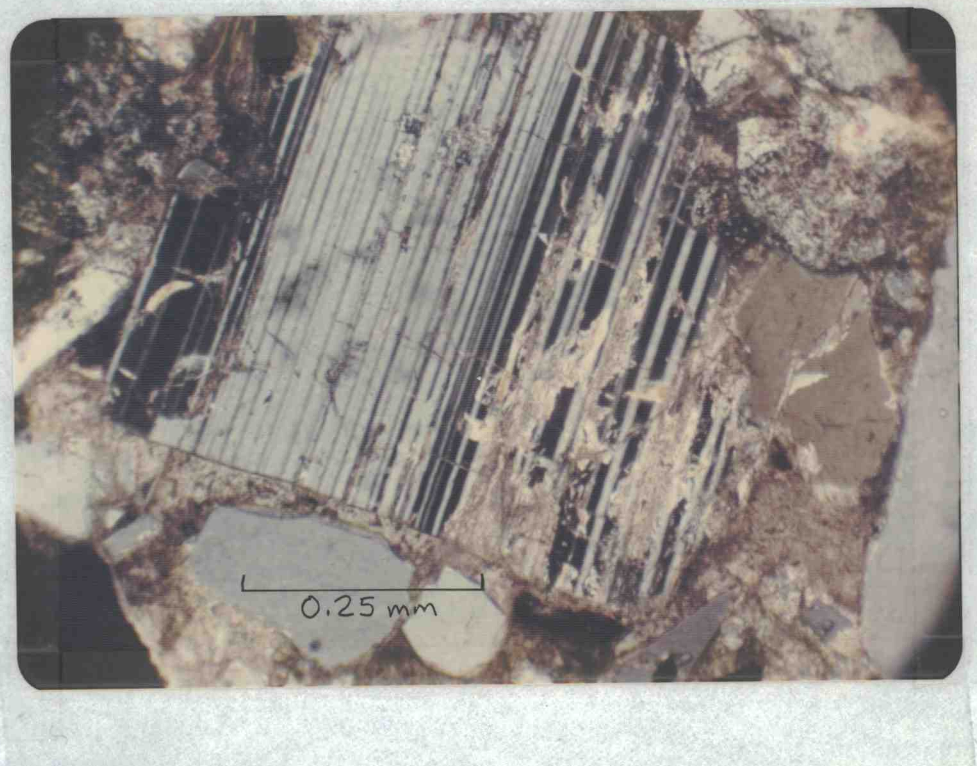


Figure 37. Photomicrograph of Geoffrey Formation concretion showing replacement of euhedral twinned plagioclase by carbonate cement. Crossed nicols. Sample 134, middle member at Parminter Point.

rock fragments is selectively replaced and results in phenocrysts suspended in sparry calcite. Extreme cases of grain replacement and resulting cement-supported textures are limited to calcareous concretions such as sample 129 from the De Courcy Formation which is 37 percent calcite.

Laumontite. Laumontite, a zeolite, occurs in sandstones of the Comox, Extension-Protection, De Courcy, and Geoffrey Formations. Laumontite was previously reported to occur widely in the Nanaimo Group but has not previously been reported from the Comox Formation (Stewart and Page, 1974). It occurs as intergranular cement (Figure 38), in veins and joint coatings, and in abundance replacing plagioclase framework grains (Figure 39). Only intergranular material was counted as cement (maximum of 10 percent). Feldspar grains which are replaced by laumontite were counted as plagioclase for purposes of sandstone classification. Therefore, the amount of laumontite recorded as a cement does not always reflect the real abundance of the mineral.

Laumontite (actually its partially dehydrated form, leonardite (Coombs, 1952)) has the following optical properties: clear; colorless; strong negative relief, refractive index less than quartz; low birefringence, about equal to quartz; two perpendicular cleavages; biaxial negative interference figure with a 2V of about 30 degrees.

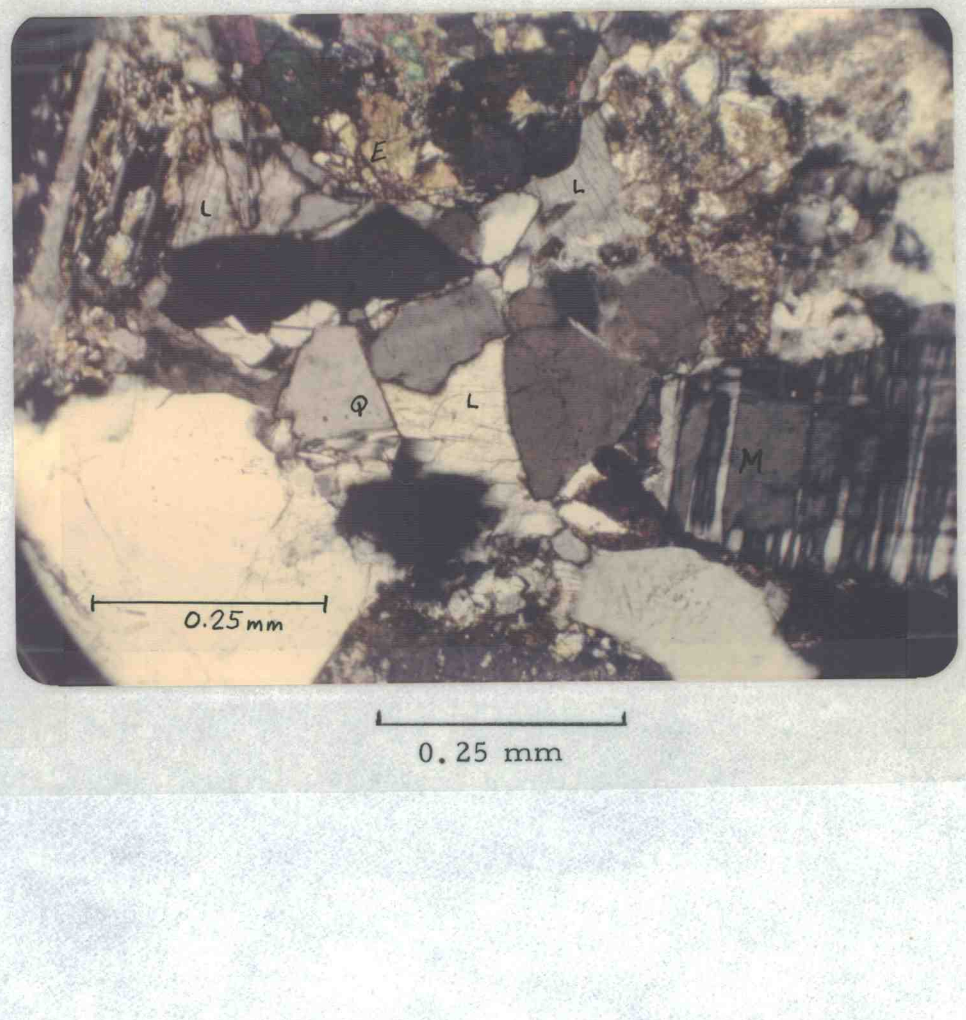


Figure 38. Photomicrograph of Comox Formation upper sandstone member arkosic arenite. Note pore-filling laumontite (L) and strong negative relief against quartz (Q), also epidote (E) and microcline (M). Crossed nicols. Sample 48.

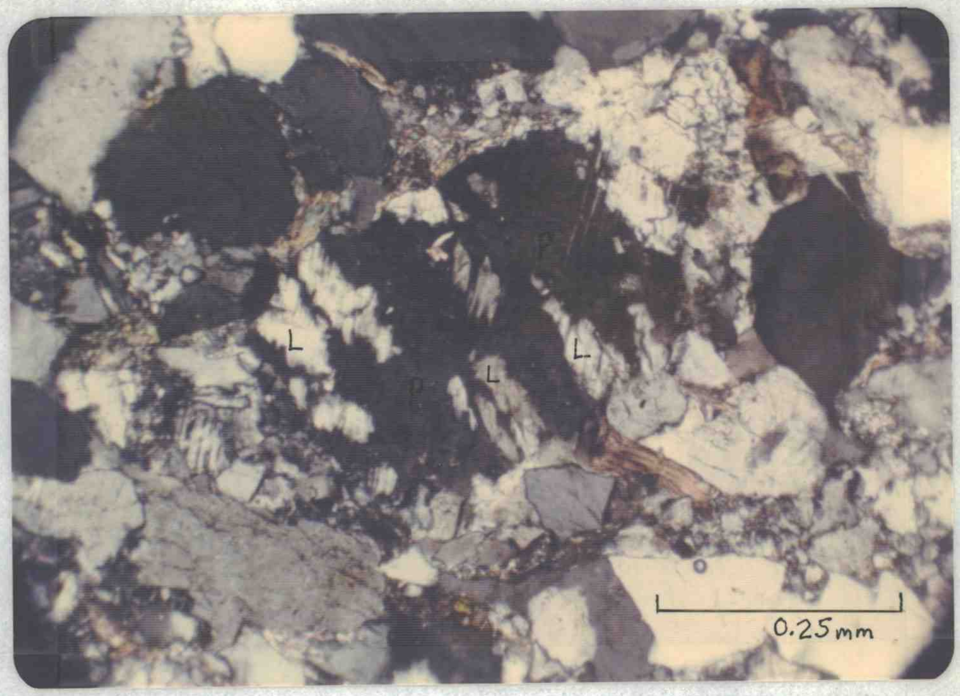


Figure 39. Photomicrographs of De Courcy arkosic arenite (arkose) showing widespread replacement of framework plagioclase (P) by laumontite (L). Note extremely tight packing, moderate sorting, angularity of grains, and local interpenetration. Crossed nicols. Above, width of field is one millimeter; below, four millimeters. Sample 124, De Courcy Tongue 3 marine sandstone.

As a cement, it occurs as optically continuous patches with distinctive cleavage. As a replacement of plagioclase, it sometimes displays a reticulate habit.

Joints coated with a mesh of minute, tabular, white zeolite occur widely in the study area. They cross conglomerate clasts and concretions. A joint coating from De Courcy sandstone along Scott Road was powdered, analysed by X-ray diffraction, and subsequently identified as leonardite, a dehydrated form of laumontite. The diffraction pattern contains the following major peaks: 9.47 Å (I_o/I_1 = 1.0); 6.83 Å (I_o/I_1 = .47; 4.16 Å (I_o/I_1 = .78); 3.50 Å (I_o/I_1 = .75); 3.27 Å (I_o/I_1 = .47).

Quartz. Minor amounts of quartz cement occur throughout the Nanaimo Group as pore fillings and optically continuous overgrowths on monocrystalline detrital quartz grains. Quartz cement ranges in abundance form 0 to 4 percent and is generally clearer than detrital grains.

Iron-oxide. Small quantities of iron-oxide cements occur in a few clean, porous sandstones in the Nanaimo Group. Iron-oxide locally imparts a red color to Comox Formation outcrops. It includes translucent yellowish-orange limonite and dark brown opaque to translucent red hematite. Iron-oxide ranges in abundance from 0 to 2 percent and occurs as pore fillings and grain coatings and also fills microfractures in individual grains.

Pyrite. Small amounts of pyrite (less than 1 percent) occur in a Comox marine sandstone (as euhedra) and in thick, graded sandstone beds of the upper Cedar District Formation.

Prehnite. Prehnite is abundant in two samples from the Comox Formation upper sandstone member (samples 71 and 123) where it occurs as radiating aggregates of colorless, lath-shaped crystals which have grown on or within and forcibly expanded biotite grains (Figures 40, 41). Prehnite masses attain one millimeter in diameter and are of post-depositional origin as shown by their association with biotite and the undeformed nature of the delicate aggregates (Figure 40). Prehnite shows the characteristic "bow-tie" structure, moderate birefringence (maximum upper second order colors), high relief, biaxial positive interference figure, low to moderate 2V (40 degrees), parallel extinction, and length-fast orientation.

Paragenesis of Cements. Several thin-sections show microscopic textural relationships indicative of the order of formation of post-depositional cements and matrix. Iron-oxide and "chloritic" grain rims and pore fillings are relatively early diagenetic products. Crystallization of quartz pore fillings post-dates formation of iron-oxide and chloritic pore linings; in several thin-sections, quartz completely fills voids which are lined with the latter two materials. Laumontite seals pores which are lined with iron-oxide and others which are partially filled by quartz overgrowths (as in sample 48)

Figure 40. Photomicrographs of Comox Formation upper sandstone member arkosic arenite. Above, crossed nicols, microcline (Mi), hornblende (H), plagioclase (P), metamorphic rock fragments (M), epidote (E), quartz (Q), and prehnite (Pr). Below, plane light, note good sorting, tight packing, and delicate prehnite growths at arrows. Sample 123.

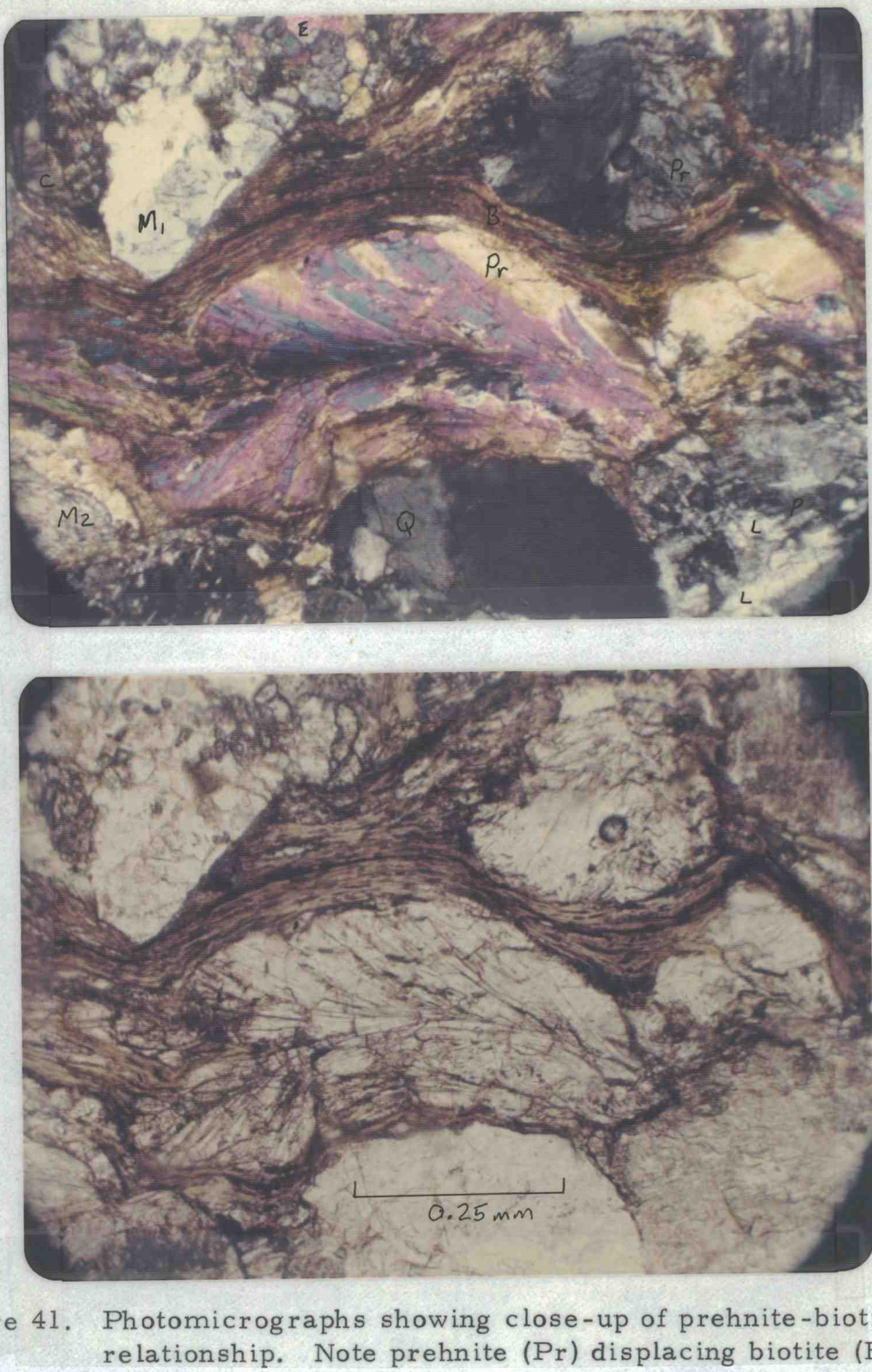


Figure 41. Photomicrographs showing close-up of prehnite-biotite relationship. Note prehnite (Pr) displacing biotite (B). Also occurring are metamorphic rock fragments (M1 and M2), epidote (E), polycrystalline quartz (Q), plagioclase (P), chlorite (C), and laumontite (L) replacing plagioclase. Above, crossed nicols; below, plane light. Sample 123.

or euhedral vuggy quartz (as in sample 62). However, another possible explanation cannot be dismissed; pore-lining iron-oxide could post-date laumontite if it were deposited in a crack surrounding laumontite which shrank upon dehydration. When not in an aqueous environment, laumontite rapidly dehydrates. Cracks form as the unit cell shrinks (Coombs, 1952).

An early diagenetic origin of calcareous sandstone concretions is indicated by:

1) the lack of quartz and laumontite cements in the concretions, and concretions cut by laumontite joint coatings;
2) occurrence of "fresh" hyaline volcanic rock fragments in concretions and a lack of diagenetic matrix.

However, calcite cementation was not consistently early as indicated by limited evidence of:

1) calcite replacing diagenetic matrix (2 thin-sections);
2) calcite post-dating a laumontite vein (1 thin-section);
3) a calcite micro-vein cutting a sutured grain contact.

A definite antithetic relationship exists between calcite and laumontite; they occur together only in three thin-sections and only in trace amounts. Laumontite was not found as a cement or replacement of plagioclase grains in any of the calcareous sandstone concretions which were examined. Paragenetic relationships are summarized in Table 5.

Table 5. Paragenetic relationships in sandstones.

Sample	Unit	Chronology	
2	Kc Beaver Point	1. chloritic pore lining	2. quartz pore filling
12	Kc Yeo Point	1. chloritic pore lining	2. quartz pore filling
49	Kc middle member	1. chloritic pore lining	2. laumontite pore filling
40	Kc upper member	1. chloritic pore lining	2. quartz pore filling
48	Kc upper member	1. quartz overgrowths	2. laumontite pore filling
62	Kc upper member	1. brown fe-oxide pore lining 3. laumontite poor filling brown fe-oxide and stain laumontite	2. quartz pore filling (vuggy) 4. orange fe-oxide repl.
70	Kc upper member	1. Fe-oxide pore lining	2. laumontite pore filling
143	Kep middle member	1. detrital quartz	2. replaced by laumontite
213	Kep Ganges Harbor mem.	1. sutured grain contact	2. cut by calcite vein
219	Kcd upper member	1. laumontite vein	2. calcite fills porosity in vein
116c	Kd_1	1. Fe-oxide pore lining Authigenic quartz and feldspar relationships uncertain	2. laumontite cement
106	Kd_1	1. Fe-oxide	2. quartz cement
227	Kd_2 Southey Point	1. diagenetic matrix and detrital quartz and feldspar	2. replaced by calcite
128	Kd_3	1. detrital matrix	2. replaced by calcite
132	Kg lower	1. diagenetic matrix	2. replaced by calcite

Textural Aspects

Textural aspects determined in thin section are presented in Appendix III. Sorting was determined by visually estimating the range of grain sizes (Wentworth grades) which include 80 percent of the material. Sorting categories are as follows: well sorted, 1-3 Wentworth grades; moderately sorted, 3-5; poorly sorted, 5-7; very poorly sorted, more than 7. Grain roundness was visually compared with a chart presented by Powers (1953).

Tight packing, as evidenced by abundant sutured framework grain contacts and interpenetration and contortion of mica and fine-grained rock fragments, occurs in all formations of the Nanaimo Group. Grains were probably forced into close contact during deep burial and attendant high lithostatic pressure.

Sorting. Most sandstones are moderate to poorly sorted. A well sorted character is prevalent in only the Comox and Extension-Protection sandstones and is of limited occurrence in fine-grained Cedar District and De Courcy sandstones.

The Comox Formation black sandstone (sample 39) was dis-aggregated and sieved; a cumulative size-frequency curve was plotted on arithmetic probability paper. The resulting Inman sorting statistic, $S\phi$, is 0.75ϕ units which is indicative of a very well sorted sand and further substantiates its deposition in a high energy beach environment (Royse, 1972).

Roundness. Most mineral grains in Nanaimo Group sandstones are angular to subangular; euhedral feldspar grains are common. Rare rounded quartz grains were probably recycled from older sedimentary rocks.

Maturity. Most Nanaimo Group sandstones are texturally immature or submature because of the abundant detrital matrix, poorly sorted nature, and subangular grain shapes (Folk, 1951). The level of maturity records, in general, a history of rapid erosion, deposition and burial, and a lack of extended exposure to vigorous waves and currents. Immature sandstones, characterized by greater than five percent detrital matrix, include fluvial sandstones of the Extension-Protection Formation middle member, proximal turbidites and pebbly mudstones of the upper Cedar District Formation, De Courcy marine sandstones including those with dish structures, and Geoffrey Formation fluvial-marine sandstones.

Texturally submature sandstones, characterized by less than five percent matrix, poor sorting, and angular grains, are also common and include littoral and fluvial sandstones of the Comox and Extension-Protection Formations. In many cases, evaluation of textural maturity is hindered either by the replacement of matrix and framework grains by calcite or by the inability to determine the content of detrital matrix in the presence of abundant diagenetic matrix.

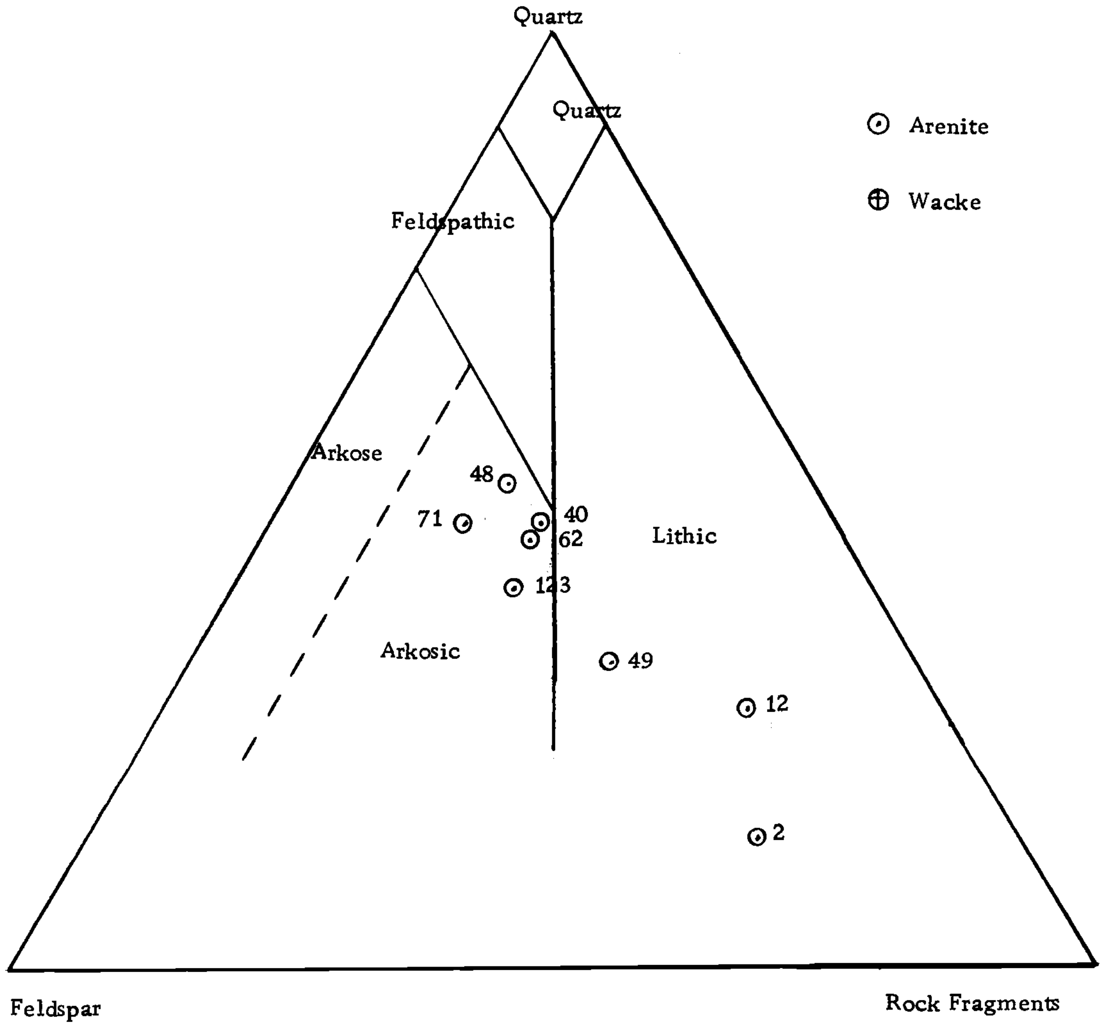


Figure 42. Classification of Comox Formation sandstones.

Texturally mature sandstones are clean, well sorted, and have subangular to subrounded grains. Only a few samples can be unequivocably assigned to this class; most are littoral sandstones of the Comox and Extension-Protection Formations. Several sandstones are clean and well sorted, but lack grain roundness necessary for classification as mature sandstones; probable shallow marine sandstones of the Cedar District and Northumberland Formation "platy facies" and a few Comox fluvial sandstones show such characteristics.

Classification of Sandstones

Nanaimo Group sandstones were classified using Gilbert's classification (Williams, Turner, and Gilbert, 1954). The method is relatively simple, widely used among geologists, primarily descriptive, has a minimum of genetic implications, and is applicable to rocks of the Nanaimo Group. The Gilbert classification is based upon two criteria:

1) two suites of sandstones are differentiated on the basis of fine-grained intergranular matrix: wackes contain greater than 10 percent matrix and arenites contain less than 10 percent matrix;
2) a ternary plot of the relative abundance of stable and unstable grains, in which each apex of a triangle represents one of three categories - quartz plus chert (Q), feldspars

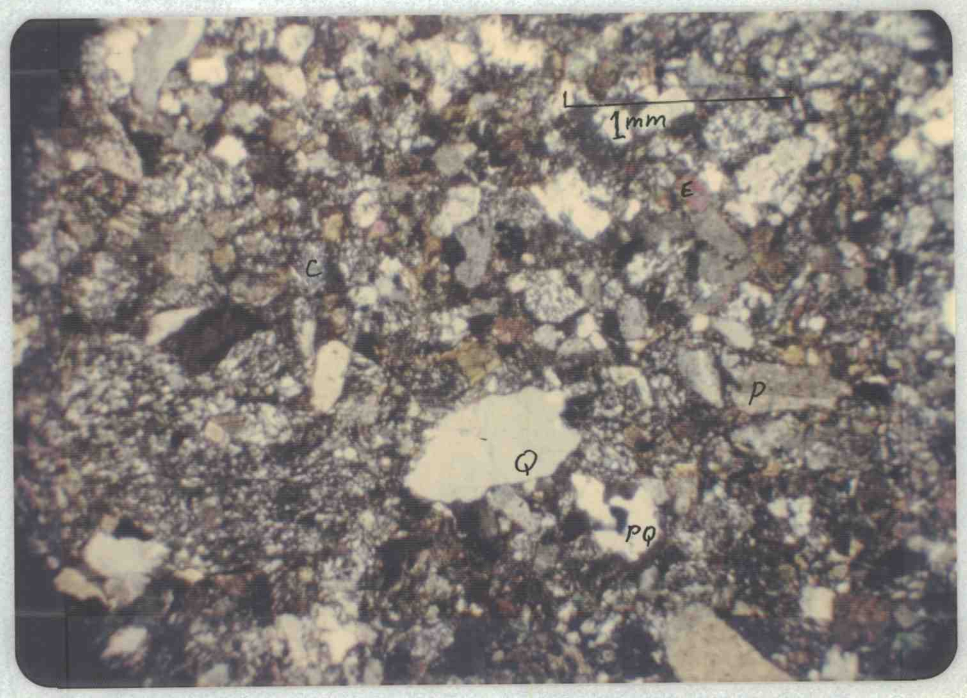


Figure 43. Photomicrograph of Comox marine lithic arenite from Beaver Point. Note abundant polycrystalline quartz (PQ), quartz (Q), epidote (E), chert (C), and cloudy plagioclase (P). Crossed nicols. Sample 2.

(F), unstable fine-grained rock fragments (R) - is used to define specific types of wackes and arenites.

Comox Formation. Comox Formation sandstones show the widest compositional variation (Figure 42) and probably owe this character to local derivation from a lithologically heterogeneous basement. All eight samples are arenites and reflect deposition in either high-energy marine or high-gradient fluvial channel environments. Basal marine sandstones of Beaver Point and Yeo Point are lithic arenites and owe their green color to an abundance of greenschist and greenstone fragments, chloritic cement, and detrital chlorite and epidote. Sandstones of the upper member are more enriched in feldspar than the basal marine sandstones and plot as arkosic arenites. However, these sandstones, too, contain a high content of metamorphic rock fragments (Figure 40). For all samples, the proportion of feldspars is rather constant (18-34 percent) and the content of rock fragments varies inversely with quartz.

Although compositionally diverse, Comox sandstones can be differentiated from other stratigraphic units on the basis of one or more of the following criteria:

1) high content of metamorphic rock fragments;
2) high content of polycrystalline and undulatory quartz;
3) high content of microcline;
4) post-depositional prehnite plus laumontite assemblage;

5) the specific detrital minerals actinolite, blue-green hornblende plus green hornblende, abundant epidote and chlorite.

Extension-Protection Formation. Sandstones of the Extension-Protection Formation are also compositionally heterogeneous. All are arenites; two are lithic arenites which contain abundant metamorphic rock fragments and chert (Figure 44). Six of the sandstones are arkosic arenites in which quartz (39-54 percent) and feldspars (35-52 percent) vary inversely and rock fragments are confined to a narrow range (7-13 percent).

Cedar District Formation. Cedar District Formation sandstones consist of five wackes and one arenite. The wackes contain a detrital matrix as a result of deposition from turbidity currents and fluidized sediment flows (see Discussion of Depositional Processes). Four of the samples plot as arkosic wackes and one as a lithic wacke (Figure 45). One is an arkosic arenite (Figure 46). Sample 81, from a channelized bed in a turbidite sequence (Figure 21), is relative enriched in feldspar and plots far to the left as an "arkose"; the low content of rock fragments may be a result of the small grain size (fine- to medium-grained sandstone).

De Courcy Formation. De Courcy Formation samples consist of ten arenites and seven wackes (Figure 47). Six of the wackes have appreciable diagenetic matrix and could have been deposited as arenites. All plot as arkosic sandstones, and several fall within the

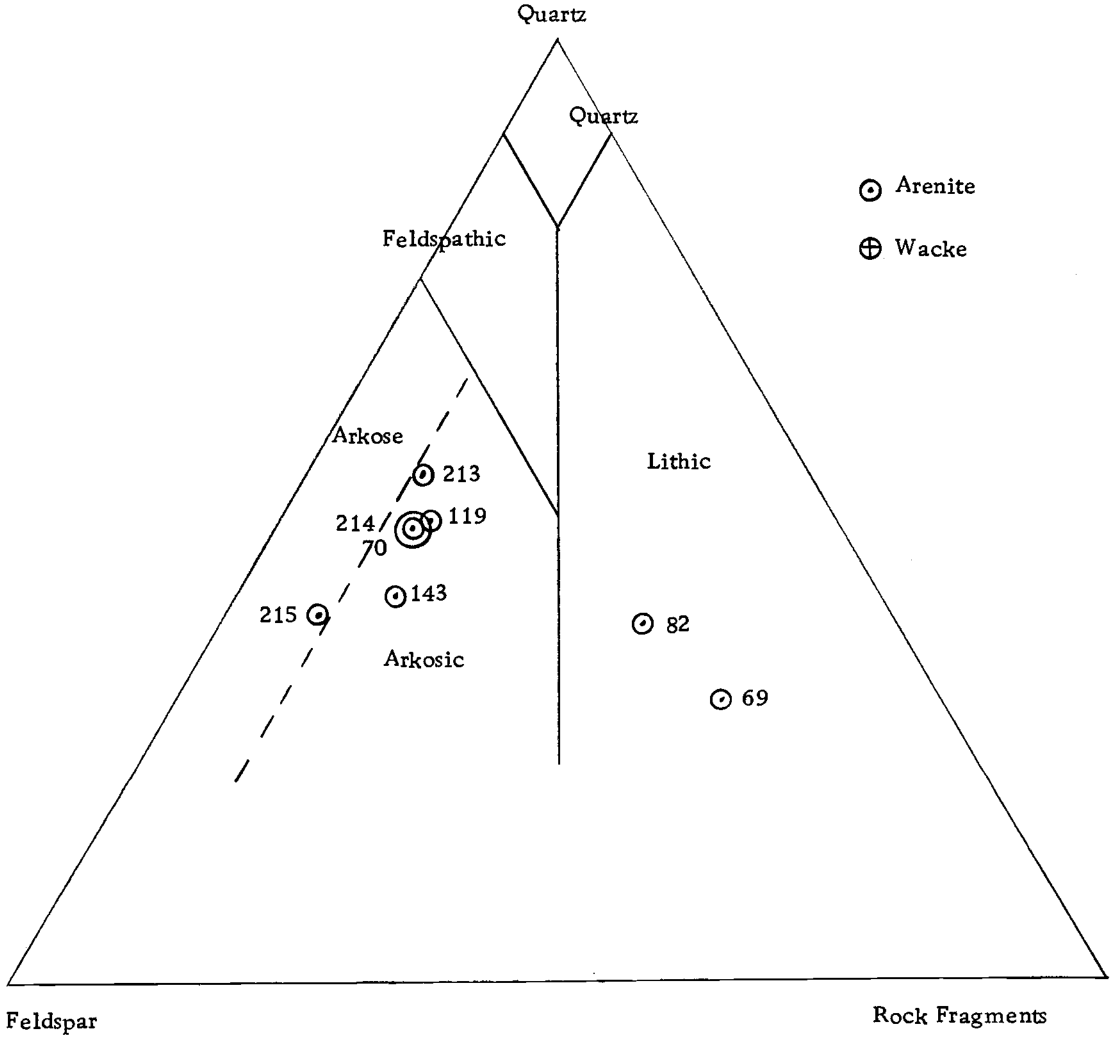


Figure 44. Classification of Extension-Protection Formation sandstones.

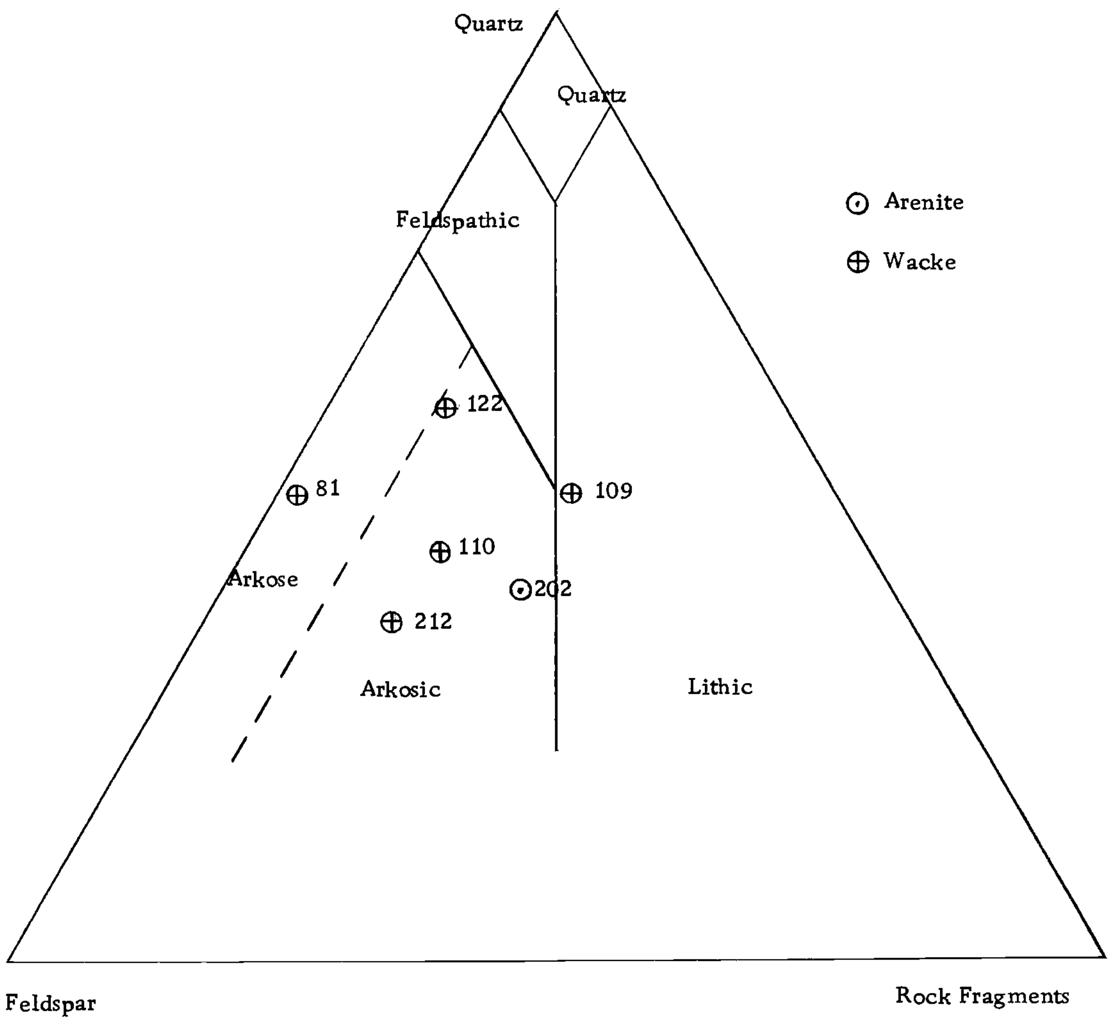


Figure 45. Classification of Cedar District Formation sandstones.

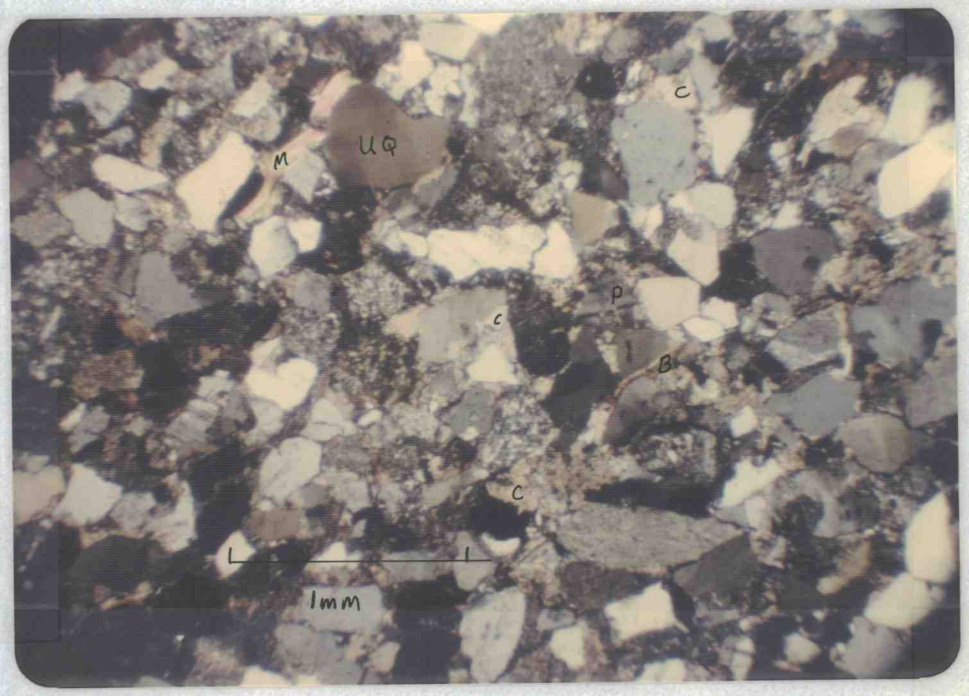


Figure 46. Photomicrograph of upper Cedar District Formation arkosic arenite showing intergranular calcite cement and replacement of framework grains. Note calcite cement (C), plagioclase (P), undulatory quartz (UQ), muscovite (M), biotite (B). High degree of sorting is not typical. Crossed nicols. Sample 202.

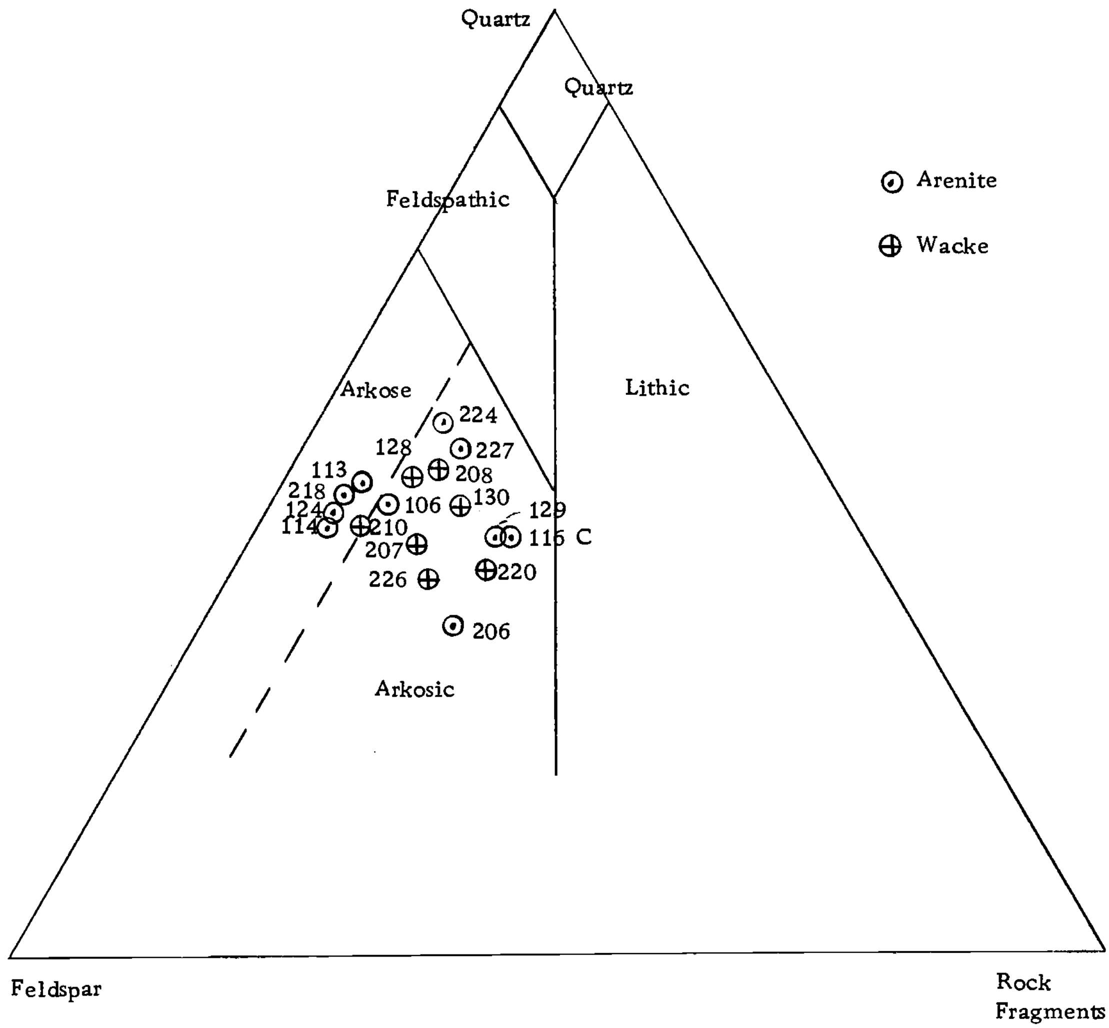


Figure 47. Classification of De Courcy Formation sandstones.

"arkose" field. The ternary plot shows a tight spacing which reflects the restricted compositional range of the De Courcy sandstones.

Geoffrey Formation. Geoffrey Formation samples consist of six wackes and six arenites. Ten plot as arkosic sandstones (five wackes (Figure 49) and five arenites (Figure 50)) and two plot as lithic sandstones (one wacke and one arenite) (Figures 48 and 35). All wackes have an appreciable content of diagenetic matrix and may have been originally deposited as arenites. Three of the arenites (samples 131, 134, 234) have abundant calcite cement which has replaced matrix and framework grains.

Compared to the De Courcy Formation sandstones, those of the Geoffrey Formation are slightly enriched in rock fragments (R = 17-36 percent, F = 26-50 percent, Q = 32-57 percent), particularly volcanic rock fragments.

Heavy Minerals

Heavy minerals were identified in thin-section and a limited number of grain mounts. Five concentrates of heavy minerals were extracted from 3-4ϕ fractions of disaggregated sandstones by flotation removal of light minerals in tetrabromoethane (specific gravity 2.96). Results of grain mount identification are presented in Appendix V. In addition, the 3-4ϕ fraction of sample 39 - Comox beach placer - was subdivided into six fractions according to magnetic susceptibilities

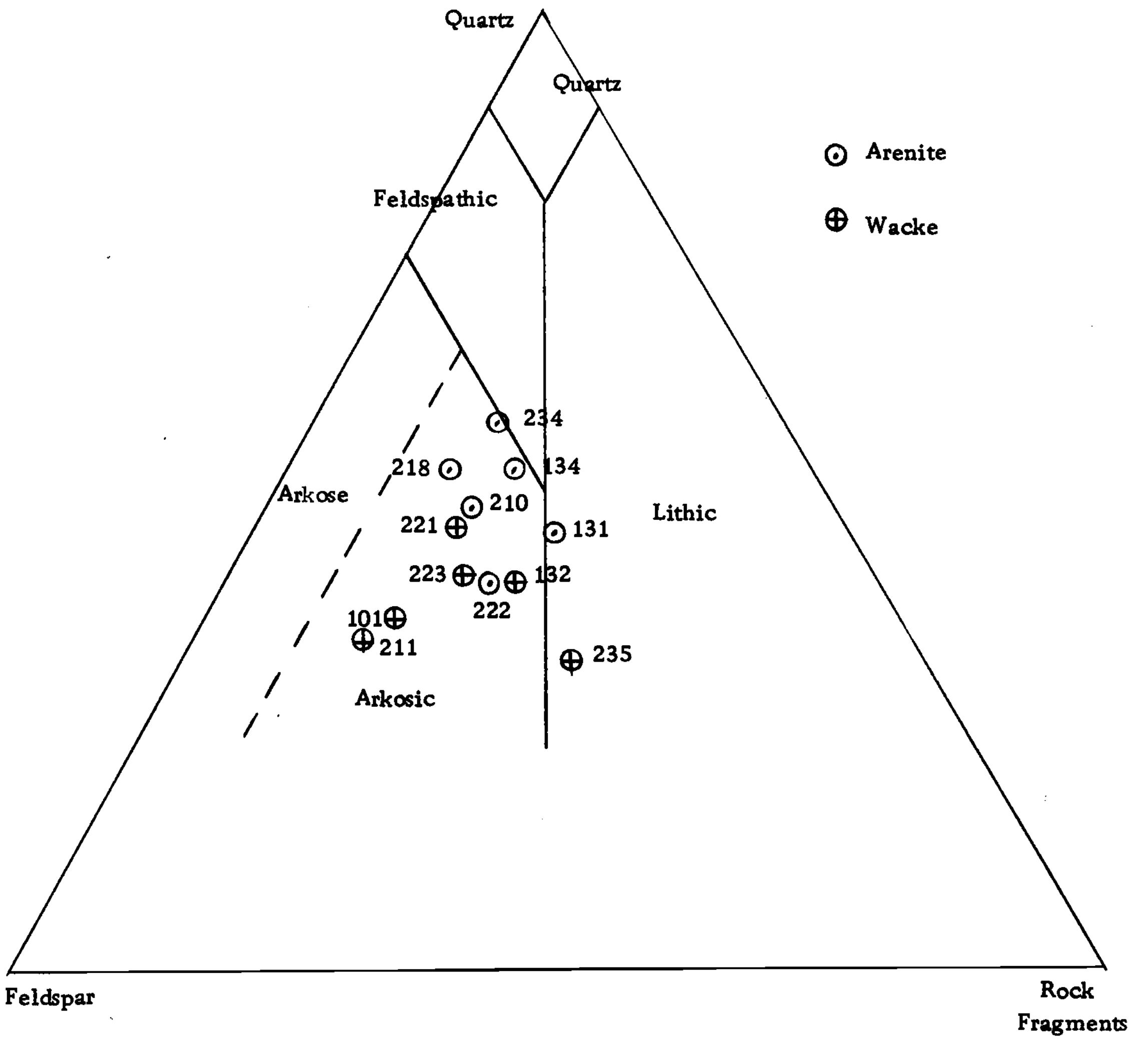


Figure 48. Classification of Geoffrey Formation sandstones.

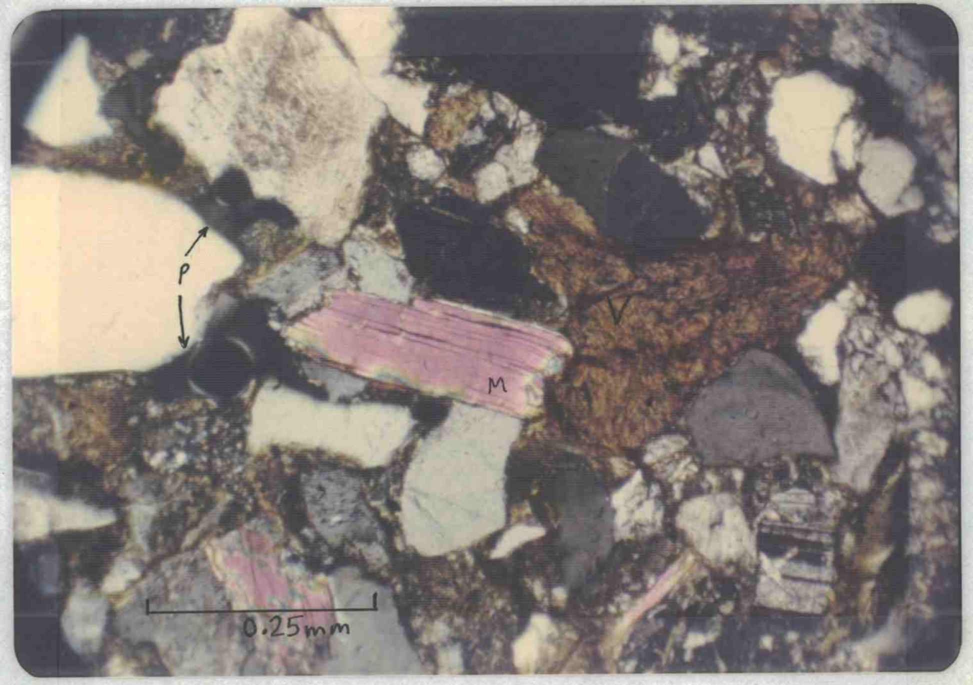


Figure 49. Photomicrograph of Geoffrey Formation arkosic wacke showing altered volcanic rock fragment (V) and transition into diagenetic micaceous matrix. Note muscovite (M), porosity (P). Crossed nicols. Sample 223.

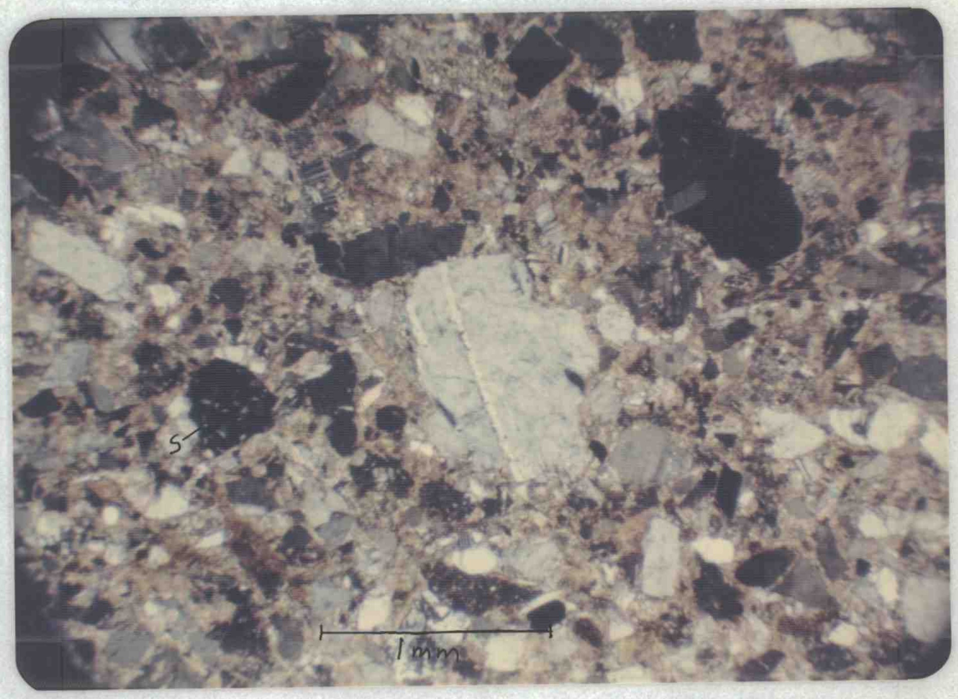


Figure 50. Photomicrograph of Geoffrey Formation upper sandstone member arkosic arenite. Note extensive replacement of framework grains by carbonate and sericite (S) on plagioclase. Sample 234, Nose Point. Crossed nicols.

with a Frantz Isodynamic Separator Model L-1 (Appendix VI).

Several heavy mineral species are common throughout the Nanaimo Group: epidote, biotite, chlorite, muscovite, angular sphene, angular clear garnet, magnetite, leucoxene, and hematite. Euhedral zircon is quantitatively rare but widely distributed. Green hornblende, blue-green hornblende, actionolite, and pyroxenes (clino- and orthopyroxene) are characteristic of the Comox Formation. Green hornblende and euhedral apatite are characteristic of the Geoffrey Formation.

As counted in thin-section, heavy minerals, excluding micas, are more abundant in the Comox (19 percent), Extension-Protection (2.4 percent), and Geoffrey (2 percent) Formation sandstones than in the Cedar District (1 percent) and De Courcy (1 percent) Formation sandstones. This difference in abundance reflects transport by competent fluvial and marine agents and concentration of heavy minerals as lag deposits in fluvial channels and beaches of the Comox, Extension-Protection, and Geoffrey Formations. Conversely, the low abundance in Cedar District and De Courcy sandstones is a result of transportation by less competent turbulent suspensions (turbidity currents) and slurries (sediment flows) which were not capable of concentrating heavy minerals.

Comox sample 39 is composed of 71 percent (by volume) opaque minerals. They are, in decreasing order of abundance: magnetite, ilmenite, leucoxene, hematite, and probable chromite. Seven percent of the rock is composed of nonopaque heavy minerals. The most abundant are epidote (including zoisite), green hornblende, euhedral zircon, a variety of garnets, sphene, and a yellow-green chloritic alteration product. A final separate, nonmagnetic at 1.2 amperes, consists of euhedral zircon, brown sphene, leucoxene, angular zircon, rounded zircon, and rare rutile.

Impure Limestones

Four thin-sections of impure limestone, three from the upper Cedar District Formation and one from the Northumberland Formation, were examined. Composed of detrital clay, microcrystalline carbonate and subordinate detrital silt, they are best termed calcareous mudstones or silty argillaceous limestones. In thin-section, they resemble silty micrites (Folk, 1962). However, the term micrite is technically improper because the microcrystalline carbonate is probably predominantly if not totally of diagenetic origin and was not deposited as a carbonate ooze.

Two of the samples are thinly laminated with alternating silt-rich and silt-poor laminae. Two others have swirls and streaks of silty microcrystalline carbonate in a microcrystalline carbonate matrix.

Microcrystalline carbonate and clay, collectively, range in abundance from about 60 to 95 percent. The carbonate shows traces of recrystallization to microspar. Silt-size detritus, consisting of quartz, plagioclase, muscovite, biotite, chlorite, hornblende and zircon, is well sorted, angular, and shows evidence of marginal replacement by microspar.

Minute burrows and pockets of fecal pellets occur in three of the samples. Minor constituents include carbonaceous flakes, traces of collophane, up to one percent pyrite associated with brown stain (sapropel?), and circular microfossils (about 0.07 millimeter diameter) filled with microspar.

Possibly all of the limestones examined are carbonate concretions of mudstone and siltstone. The laterally persistent beds may have resulted from selective cementation of well sorted and permeable siltstones. Evidence of a replacement origin includes:

1) occurrence of calcareous bodies in all gradations from small ellipsoidal concretions to lenses and laterally persistent beds;
2) widespread evidence of replacement of detrital silt grains;
3) locally advanced carbonate replacement of framework grains in associated sandstone beds.

Coal

Coal from a seam in the Southey Point member of the De Courcy Formation (Kd_2, Measured Section K-L) is tentatively classified as a dull clarain. In hand specimen, it is fairly hard and strong, grayish black (N2), and has yellow-orange stain along fractures. The coal is composed predominantly of vitreous and laminated clarain and has subordinate lenses of charcoal-like fusain and rare discernible wood fragments.

A thin-section cut perpendicular to bedding is composed of an estimated 97 percent vitrinite and 3 percent resinite (Milner, 1962). Vitrinite is blood-red in "ultra-thin-section" (otherwise opaque), thinly laminated, and slightly birefringent with aggregate extinction parallel to the bedding plane. Resinite occurs as golden yellow isotropic lenses less than 1 millimeter thick and a maximum of 3 millimeters long. The coal is probably subbituminous in rank because of similarities to coals of the Extension-Protection Formation Wellington Seam described by Hacquebard and others (1967; in Muller and Jeletzky, 1970).

Clay Minerals of Mudstones and Siltstones

The clay fractions of ten samples of mudstone and siltstone were analysed by X-ray diffraction. Identifications and collection localities are presented in Appendix VII.

Analytical Procedure

Clay minerals were identified by X-ray diffraction using a Norelco diffractometer. Sample preparation included fractionation, clean-up pretreatments, and characterization treatments.

Each sample was disaggregated by gentle grinding, dry screened through a 230-mesh screen, and fractionated by centrifuging. The less than 2 micron fraction was retained for analysis. Pretreatments consisted of calcium carbonate removal with 0.1 normal hydrochloric acid, organic matter removal with hydrogen pyroxide, and iron removal with sodium citrate and sodium dithionate.

Characterization treatments were used to control cation saturation and hydration. Samples were split and magnesium- and potassium-saturated subsamples prepared by washing with 1 normal magnesium and potassium chloride solutions. Oriented mounts were prepared by smearing the clay paste onto glass slides (Theisen and Harward, 1962). Five traces were run of each sample: (1) potassium-saturated and dried at room temperature and humidity, (2) magnesium-saturated and dried at room temperature and humidity, (3) magnesium-saturated and solvated with ethylene glycol by condensation of the vapor, (4) potassium-saturated and heated at 300°C - for 3 hours, (5) potassium-saturated and heated at 550°C. for 3 hours.

Instrumental settings were as follows: Radiation Cukα at 35 KV and 35 MA; Ni filter; .006'' receiving slit; rate meter setting mult. 1 x 10^3 with a time constant 2; scan rate 1^o per minute. Traces 1 and 2 were scanned from 2^o to 20^o 2θ, and traces 3, 4, and 5 were scanned from 4^o to at least 13^o 2θ.

Identification Criteria

Five dominant clay mineral groups are identified: mica, chlorite, kaolinite, chloritic intergrade, and smectite. A minor component in some samples is a 24 to 26 Å regularly interstratified system.

Mica and chlorite are recognized by 10 Å and 14 Å reflections, respectively, which persist regardless of saturating cation, solvation, and heat treatment. In addition, sharp and intense higher order, (002) and (003), reflections occur for both minerals.

Chloritic intergrade is recognized by a broad peak or zone of reflection (plateau) between 10 Å and 14 Å. Its properties, resistance to collapse upon potsssium saturation and heating, and resistance to expansion upon magnesium saturation, are intermediate between chlorite and vermiculite.

X-ray identification of kaolinite in the presence of chlorite remains difficult because kaolinite reflections overlap even-order chlorite reflections. Kaolinite has a 7 Å basal spacing regardless of saturating cation and solvation, but decomposes at 550° C. Therefore, a sample which contains both kaolinite and chlorite should show a reduction of the intensity (peak height) of 7 Å relative to 14 Å reflections after 550° C. treatment. Because this reduction of intensity occurred for all samples, kaolinite is suspected. However, identification of kaolinite is made with reservation. Increased intensity of (001) 14 Å and decreased intensity of (002) 7 Å and (003) 4.7 Å chlorite peaks has been reported (Brindley, in Brown, 1961). Therefore, an alternative explanation is possible for the change of relative intensity of 7 Å reflections.

Montmorillonite is characterized by expansion to a 16 to 17 Å basal spacing upon glycolation of magnesium-saturated samples. Collapse to 10 Å occurs upon potassium saturation and heat treatment. In contrast to mica, kaolinite, and chlorite, montmorillonite peaks are broad and higher orders are weak.

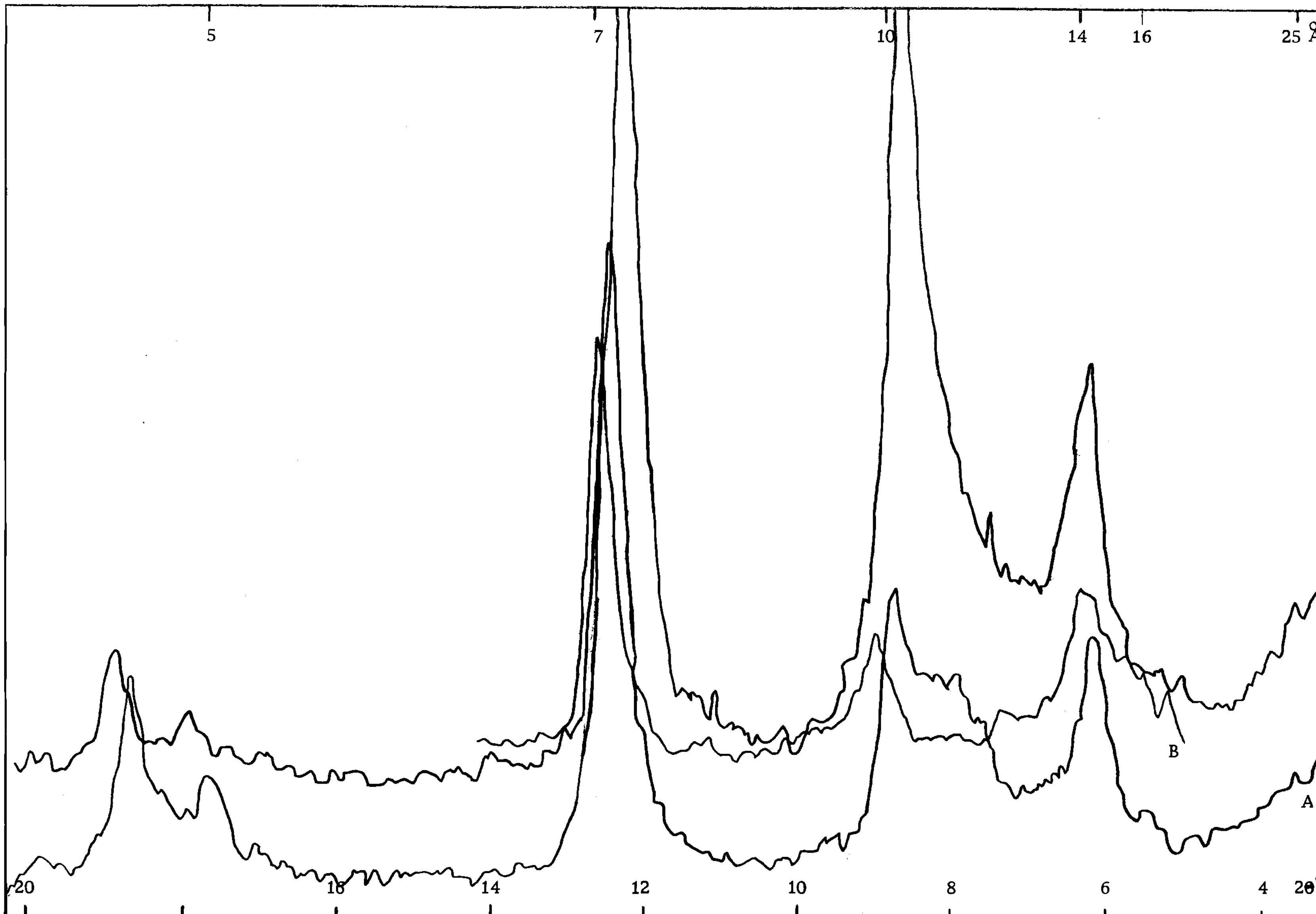
A regular interstratification of 10 Å and 14 Å material, probably a mica-montmorillonite, is recognized by 24 to 26 Å peaks. Because the peaks are very weak and not present for all characterization treatments, the exact nature of the interstratified components is not known.

Stratigraphic Distribution

Quantitative estimation of each clay component was not attempted. No X-ray diffraction technique exists which compensates for numerous variables present in the Late Cretaceous mudstones. Complicating variables include: (1) occurrence of up to six clay species in a sample, (2) occurrence of discrete and mixed-layer members in the same sample, (3) variation of diffractive ability of each clay species according to individual compositions, particle size distributions, degrees of crystallinity, and reactions to heat treatments. However, some semi-quantitative conclusions are justifiable. The very low intensity and sporadic resolution of 24 Å to 26 Å peaks indicate that the interstratified clay is a minor constituent in the samples.

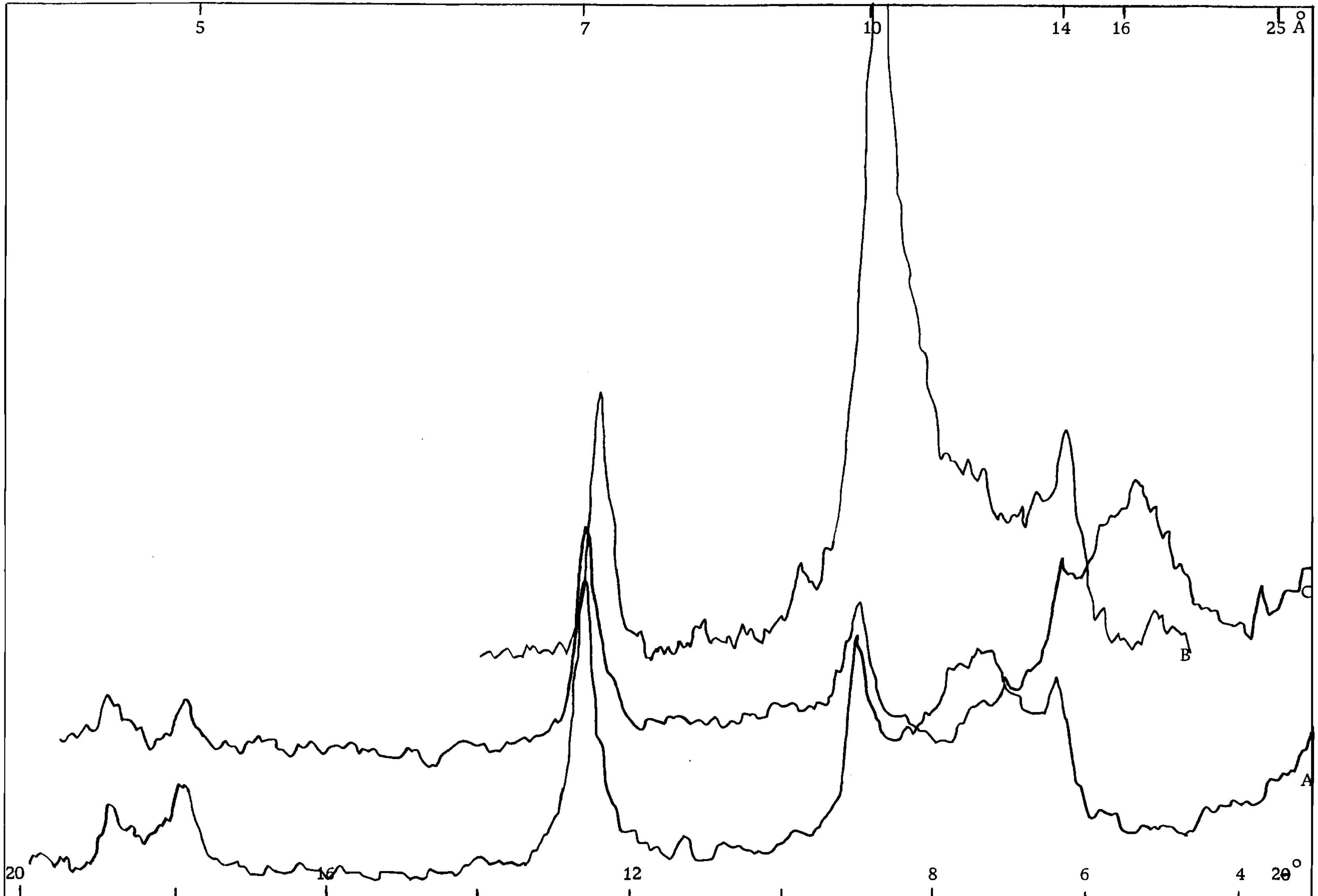
Clay mineral assemblages of the Haslam and Comox Formations show two major differences from clay mineral assemblages of the younger Northumberland, Geoffrey, and Spray Formations (Figures 51 and 52). Haslam and Comox Formation samples exhibit much sharper and more intense reflections. This may be a result of higher degrees of crystallinity than for corresponding clay minerals of the younger formations. Also, montmorillionite, at most a very minor and sporadic component in the Haslam and Comox samples, is an ubiquitous and major component in the Northumberland, Geoffrey,

Figure 51. Diffraction record of Haslam Formation mudstone (H-73) clay fraction. Characterization treatments: A = potassium saturated and run at room temp. and humidity; B = potassium saturated and heated at 550° C; C = magnesium saturated and solvated with ethylene glycol.



5
7
10
14
16
25 Å
20
16
14
12
10
8
6
4
2θ°
A
B
C

Figure 52. Diffraction record of Northumberland Formation mudstone (102) clay fraction. Characterization treatments: A = potassium saturated and run at room temp. and humidity; B = potassium saturated and heated at 550° C; C = magnesium saturated and solvated with ethylene glycol.


5
7
10
14
16
25 Å
C
B
A
20
16
12
8
6
4
2θ°

and Spray Formation samples. These differences could be a result of:

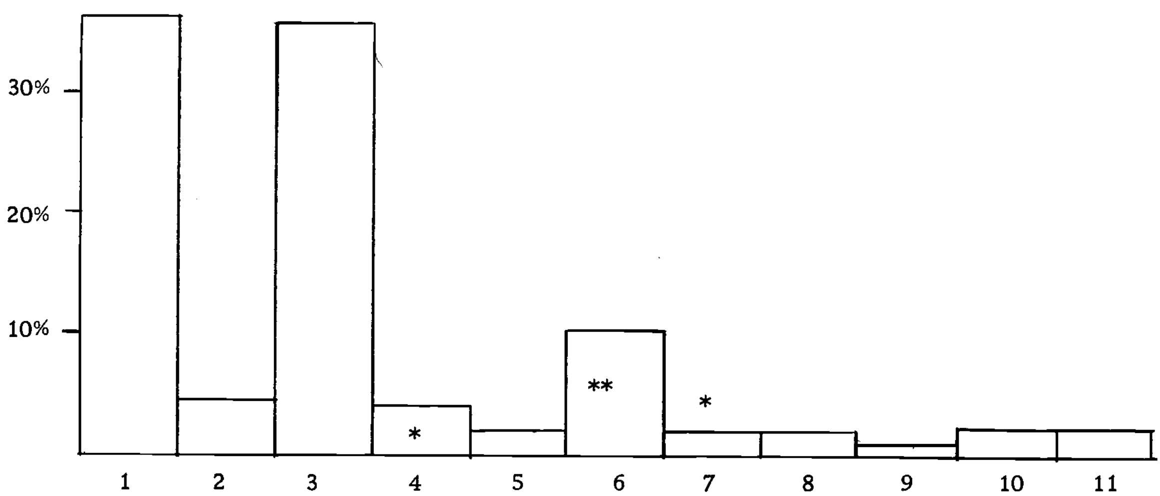
1) different provenance, with the occurrence of montmorillonite in the upper part of the Nanaimo Group indicating a greater volcanic contribution;

2) diagenetic alteration of montmorillonite to illite and mixed-layer clays in the Haslam and Comox Formations as a result of deeper burial and slightly elevated temperature (Weaver and Beck, 1971).

Lithology of Conglomerate Clasts

Conglomerate clasts were sampled at 24 localities and returned to the laboratory for identification. Sampling consisted of randomly collecting or dislodging at least 100 medium pebbles to small cobbles (approximately 1 to 4 inches maximum dimension) from weathered outcrops or from blocks returned to the lab. Clasts were identified by viewing freshly fractured and wetted surfaces with a 7 to 30 power binocular microscope. A few thin-sections of typical representatives of the more abundant lithologic groups and of enigmatic and exotic clasts supplemented identification of hand specimens. Results of pebble counts are presented in Figures 53, 54, 55, 56.

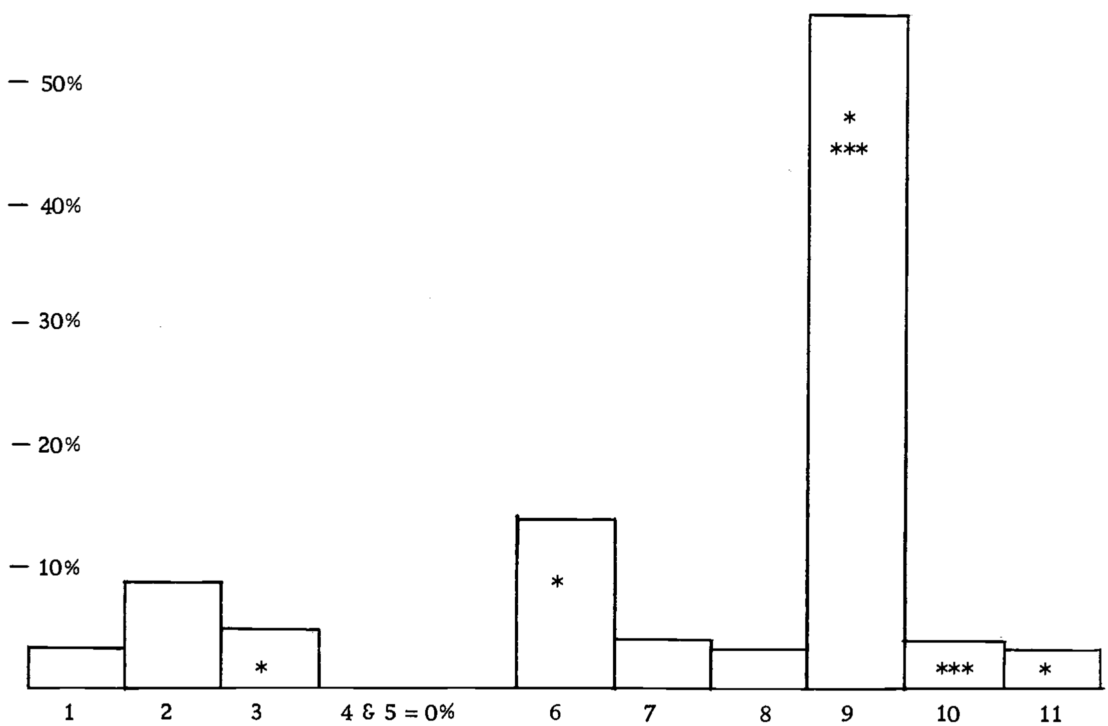
In general, the Comox Formation contains an abundance of low-grade metamorphic rocks, especially greenschist, greenstone, and



n = 861, average of 9 localities

1. Schist and phyllite
2. White quartz
3. Granodiorite to quartz diorite, including abundant altered, sheared and gneissic varieties
4. Aplite
5. Diorite
6. Andesite and abundant greenstone
7. Rhyolite to dacite
8. Basalt
9. Chert
10. Ortho- and metaquartzites
11. Other sandstone and siltstone

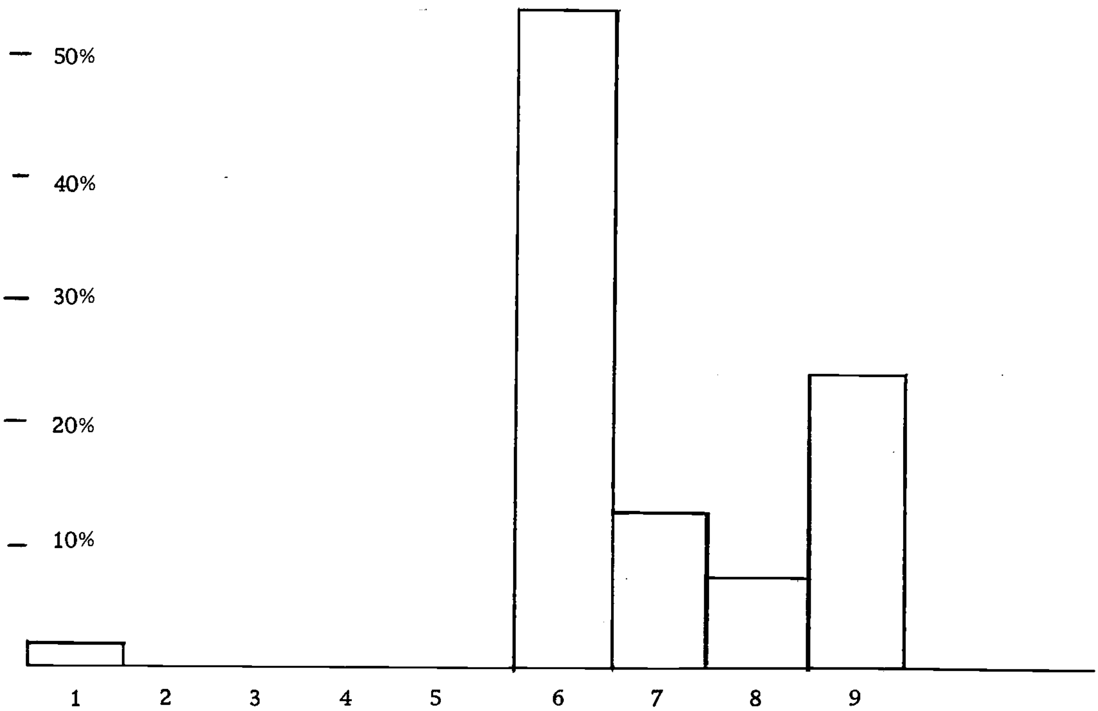
Figure 53. Summary of pebble count data for Comox Formation. * indicates confirmation by thin-section examination.



n = 919, average of 9 localities

1. Schist
2. White quartz
3. Granite to granodiorite and minor gneiss
4. Aplite
5. Diorite
6. Andesite and greenstone
7. Rhyolite to dacite
8. Basalt
9. Chert and silicified mudstone
10. Ortho- and metaquartzites
11. Other sandstone and siltstone

Figure 54. Histogram of pebble count data for Extension-Protection Formation. * indicates confirmation by thin-section examination.



n = 54, 1 locality

1. Schist

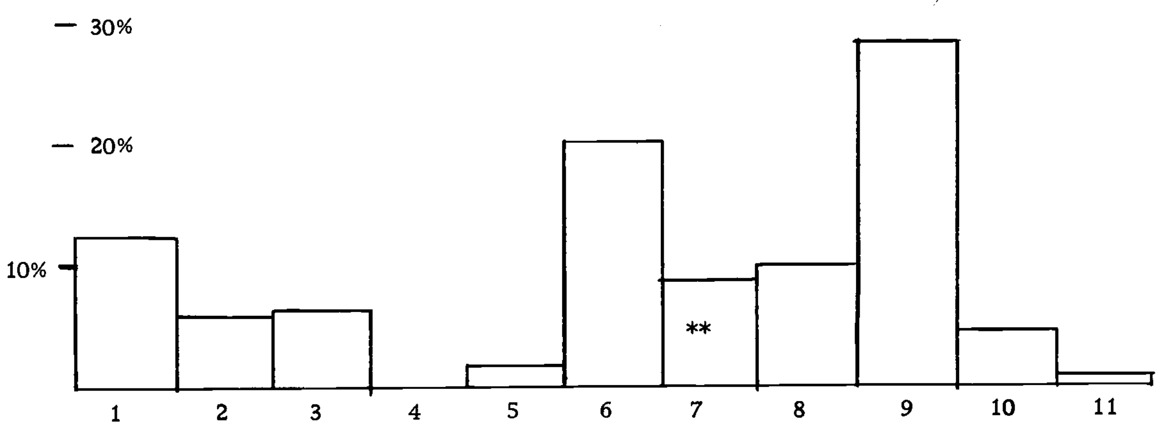
6. Andesite, andesite porphyry and minor greenstone

7. Rhyolite to dacite

8. Basalt

9. Well-indurated, pyritic mudstone

Figure 55. Histogram of pebble count from pebbly mudstone in upper Cedar District Formation at North Beach.



n = 510, average of 5 localities

1. Schist, phyllite
2. White quartz
3. Granite to granodiorite and minor greiss
4. Aplite
5. Diorite-gabbro
6. Andesite and andesite porphyry
7. Rhyolite to dacite
8. Basalt
9. Chert and silicified mudstone
10. Ortho- and metaquartzite
11. Other sandstone and siltstone

Figure 56. Histogram of pebble count data for Geoffrey Formation. * indicates confirmation by thin-section examination.

slightly foliated to gneissic granodiorite. Many of the clasts are identical to rocks found in the basement complex on Saltspring Island (greenschist and greenstone of the Sicker Group; granodiorite, gneiss and aplite of the Tyee Intrusion). (A Comox pebbly sandstone near Eleanor Point is very rich in clasts of the distinctive Sicker Group grayish green dacite porphyry which crops out near Beaver Point.)

Extension-Protection Formation conglomerates contain abundant chert and silicified mudstone and are enriched in fresh andesitic volcanics, relative to the Comox Formation. Cherts are commonly cut by numerous quartz veins and show a microscopic texture analogous to so-called "radiolarian cherts."

Conglomerates of the Geoffrey Formation are characterized by an abundance of chert and unmetamorphosed porphyritic volcanics of rhyolite to andesite composition.

Conspicuous in the Comox, Extension-Protection, and Geoffrey Formations are clasts of nearly pure quartz sandstone (quartz arenites or orthoquartzites) and metamorphosed quartz sandstone (metaquartzite). The quartzites are white and pink and contain well rounded and sorted grains which are thoroughly cemented by quartz overgrowths. Small quantities of microcline and sericitized plagioclase occur in the quartzites.

Many problems are inherent in any attempt to determine the relative abundance of lithologic types in conglomerates. The size of clasts which are sampled can significantly influence the relative abundance of clasts (Boggs, 1969). Nanaimo Group conglomerates are extremely well indurated and the samples collected from weathered outcrops and pounded from resistant outcrops are probably biased against the less durable rock types. Black phyllite and argillite are conspicuous in the finer-grained conglomerates of the Geoffrey Formation and their true abundance may not be recorded by the pebble counts because they tend to occur as small clasts and disintegrate during weathering and removal. However, the abundance of "fresh" silicic to intermediate volcanics in the Geoffrey Formation is also apparent in fresh outcrops and is believed to reflect a real increase in their abundance relative to the Comox and Extension-Protection Formations.

STRUCTURE

Introduction

The Nanaimo Group has been deformed by both faulting and folding. The group at places unconformably overlies, and at other places is in fault contact with a Paleozoic-Mesozoic basement complex which had earlier undergone multiple deformation, locally being converted to phyllite, schist, and gneiss. Outliers of the Nanaimo Group occur today at elevations of up to 5,000 feet on Vancouver Island.

The study area is bounded to the south by a set of major east- to east-northeast-trending reverse faults, the San Juan and Leech River Faults (Figure 3). The San Juan Fault extends from the south-west coast of Vancouver Island to the southeast side of Saltspring Island where it passes through Satellite Channel southeast of Cape Keppel and Beaver Point (Plate 1) (Muller, 1975). The Leech River Fault, located south of the San Juan Fault, defines the southern boundary of the Paleozoic-Mesozoic crystalline basement complex of Vancouver Island. It juxtaposes older continental crust on the north side with uplifted Tertiary oceanic crust of the Olympic Mountains geologic province on the south side. Recent seismic events suggest that one or both of these faults may still be active (Crosson, 1972). In the context of the new global tectonics, the study area is presently within a regional stress system of north-south or northeast-southwest compression which reflects interaction of the American plate (continent) and Pacific plate (seafloor) by right lateral slip along the San Andreas and Queen Charlotte Islands fault systems (Atwater, 1970; Crosson, 1972; Mayers and Bennett, 1973).

Early workers in the Nanaimo Group recognized both faults and folds as major structural elements. Richardson (1872) noted "six or seven synclinal forms" between Galiano and Vancouver Islands and believed the three mudstone sequences between Vesuvius Bay and Erskine Point were repeated sections as a result of faulting. Clapp (1914) named four folds in the Nanaimo area from southwest to northeast, the Extension Anticline, Kulleet Syncline, Trincomali Anticline, and Gabriola Syncline. He also recognized four major strike faults in the Nanaimo area which he presumed to be reverse faults with very little displacement but marked by abrupt changes in dip of the affected strata. Buckham (1947) emphasized the structure of the Nanaimo coal fields (west of Nanaimo) as a zone of northwest-trending thrust faults. More recently, faults have been cited as the major structural features and both faults and folds related to movement of basement blocks along reactivated lines of weakness (Sutherland-Brown, 1966). A recent regional study of the Nanaimo Group cites as major structural elements a system of northwest-trending normal faults, downthrown on the southwest side, which create a

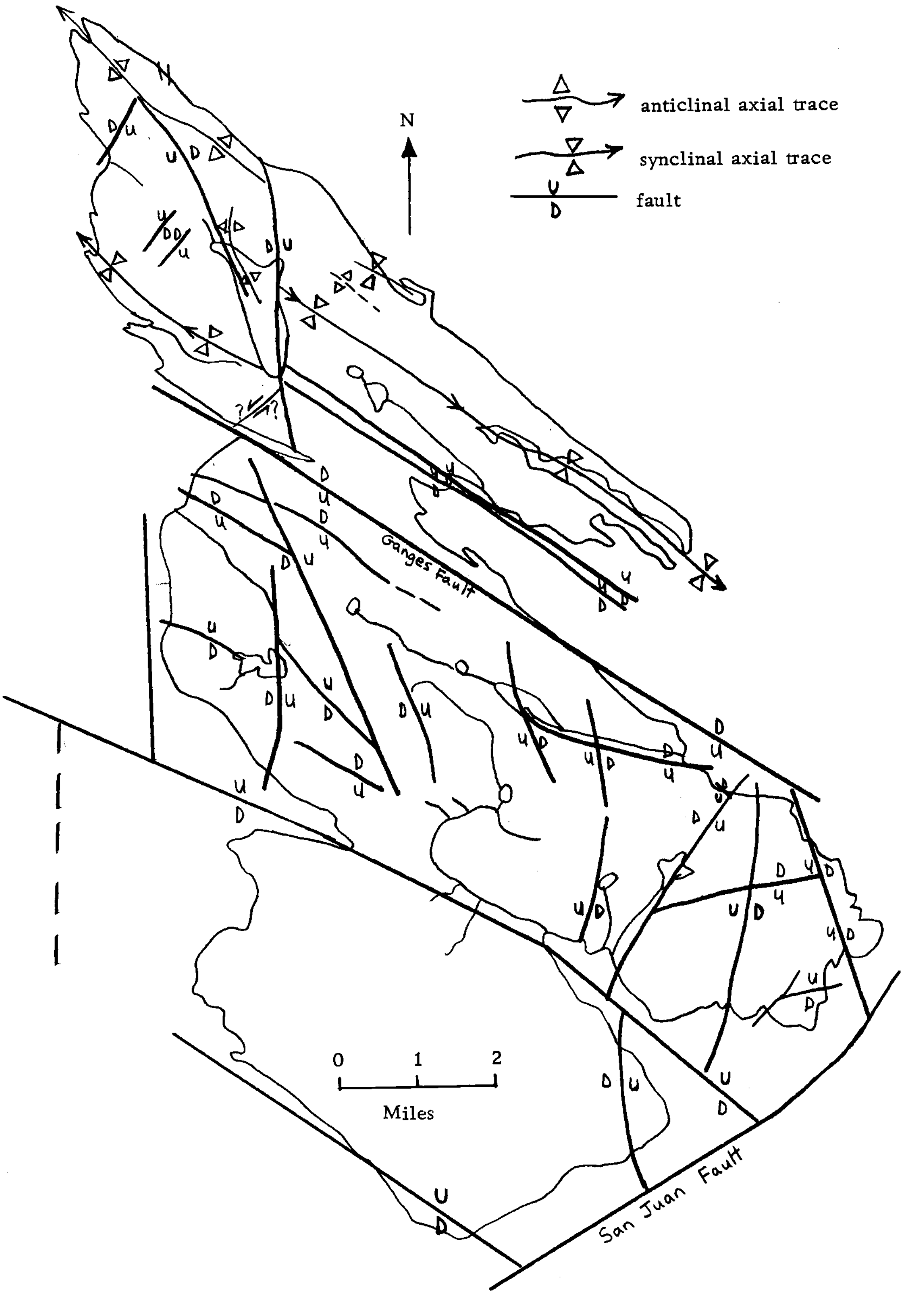


Figure 57. Structure of Saltspring Island, British Columbia.

series of gently northeast-tilted blocks. The tilted blocks preserve Cretaceous sedimentary rocks, expose strips of Paleozoic rocks along the southwestern upthrown edges, and are cut by a system of younger northeast-trending cross-faults (Muller and Jeletzky, 1970).

The structure of the thesis area consists of a system of major northwest-trending strike faults, a system of transverse faults, and three major folds (Plate 1 and Figure 57).

Folds

The axes of the Kulleet Syncline and Trincomali Anticline pass through the study area (Plates 1 and 2). The axial trace of the Kulleet Syncline extends N. 50° W. from a point near the south end of St. Mary Lake to the bay 0.13 miles northeast of Parminter Point and is delineated by northeasterly dips along the coastline between Duck Bay and Parminter Point, and by southwesterly dips in strata extending from the southwest shore of St. Mary Lake to the coastline north of Parminter Point. The syncline is asymmetric with a steep southwest limb which dips as great as 74° and a northeast limb which dips 10 to 20°. A northwest-plunging axis is suggested by the generally slightly flaring strikes in the Parminter Point area, and exposure of the Northumberland Formation along the projected axial trace at the south end of St. Mary Lake.

An en echelon syncline, with an axial trace offset 1.13 miles northeast of the axial trace of the Kulleet Syncline, extends from the east shore of St. Mary Lake to Nose Point and Scott Point at the southeast end of Long Harbor. This syncline, for simplicity, is considered to be an extension of the Kulleet Syncline, although technically it appears to be a separate en echelon fold. The axial trace trends N. 45° to 55° W. and is well defined along the east shore of St. Mary Lake and at Long Harbor. Except for the synclinal nose on the east shore of St. Mary Lake, the fold is asymmetric and characterized by a steeper southwest limb (50 to 80°) and a flatter northeast limb (30 to 40°). The fold plunges to the southeast as shown by attitudes across the axis along St. Mary Lake and preservation of the Spray Formation astride the axis in Long Harbor. A minor north-trending anticline is inferred to occupy the faulted culmination which underlies St. Mary Lake and separates the oppositely plunging en echelon segments of the Kulleet syncline.

A major anticline, developed at the north tip of the study area northeast of the Kulleet Syncline, is believed to be an extension of the Trincomali Anticline and has been mapped as such to the northwest on Thetis and Kuper Islands (Simmons, 1973). However, like the segments of the Kulleet Syncline, the anticline appears to be an en echelon fold developed northwest of and not continuously joined to the Trincomali Anticline which underlies Trincomali Channel. ~~The~~

The axial trace of the Saltspring Island segment of the Trincomali Anticline trends N. 40 to 55° W. and is recognized for a distance of three miles extending from a point 0.5 miles west of Fernwood to Southey Bay. The anticline is slightly asymmetric with a steeper northeast limb (22 to 45°) and plunges to the northwest as indicated by converging strikes in the Southey Bay area.

Six minor folds are mapped in the thesis area. Five occur along the northeast coastline between Southey Point and Walker Hook and are inferred from attitudes of coastal exposures and very limited control inland. A small symmetrical anticline intersects the coastline 0.75 miles northeast of Erskine Point and appears to be bounded by faults.

Faults

In the study area faults are recognized by the breaching of resistant sandstone and conglomerate units, truncation of dip slopes, offset of formational contacts, repetition or omission of strata, juxtaposition of stratigraphically separated formations, linear fault and fault-line scarps, extensively crushed, sheared, and slickensided zones, abrupt changes in attitude of strata, aerial photo lineations, and especially combinations of the above. The major post-Late Cretaceous structural element is a system of northwest-trending strike faults with, in some cases, vertical offsets of at least 2,000 feet. A prominent system of transverse faults trends north-northwest to northeast.

Strike Faults

At Cape Keppel, a major fault trending N. 50° W. juxtaposes sandstone and conglomerate of the Nanaimo Group with greenstone-argillite-metagabbro of the Sicker Group. The sedimentary strata dip steeply northeast toward the upthrown basement block. The southwest face of Mount Tuam is a faultline scarp of nearly 2,000 feet relief. Because Cretaceous rocks crop out at sea level, vertical separation on the fault must be at least 2,000 feet. Locally, the Haslam Formation is severely deformed, as on the southeast side of the deltaic promontory in section 33 where disharmonic folding and tectonic blocks of sandstone a few feet long occur in a sheared mudstone matrix.

Another large fault, trending N. 38° to 50° W., intersects the study area through the valley between Burgoyne Bay and Fulford Harbor and creates the distinct south and middle lobes of Saltspring Island. The fault is probably a high angle normal fault. Upthrow and tilting of the northeast block created the precipitous southwest face and gentle north slope of Mount Maxwell. Based upon the occurrence of Haslam Formation along the southwest shore of

Fulford Harbor and repetition on the north slope of Mount Maxwell, vertical separation across the fault is in excess of 2,000 feet.

A third major structural break, here called the Ganges Fault Zone, trends approximately N. 60^{o} W. from the southwest shore of outer Ganges Harbor to Booth Inlet and separates the middle and north lobes of Saltspring Island. The fault zone, exposed in a low seacliff on the southwest side of the mouth of Booth Inlet, is at least 300 feet wide and marked by closely spaced (less than 0.5 inches) near-vertical shears which obliterate stratification and trend approximately parallel to Booth Inlet. The fault zone is also exposed along the southwest shore of Ganges Harbor where, in sections 87 and 88, it consists of a zone perhaps several hundred feet wide of overturned and sheared strata. The progressive steepening and overturning of beds proceeding northeast towards the fault, suggest that the northeast side has been displaced downward. Therefore, the Ganges Fault Zone may be a high angle reverse fault. Another probable reverse fault, upthrown on the southwest side, parallels the Ganges Fault Zone on the southwest side and occurs at the northeast margin of the outcrop belt of the Extension-Protection Formation. The fault extends S. 75^{o} E. from Booth Bay at least to Mouat Provincial Park and is marked by vertically sheared conglomerate in the headland northwest of Erskine Point, overturned beds in the uppermost Extension-Protection Formation, and a fault-line scarp under the power line 0.25 miles northwest of Mouat Provincial Park. Approaching the fault from the southwest, dips in the Extension-Protection Formation progressively increase from 20° to vertical or locally overturned.

Yet another possible reverse fault parallels Cusheon Creek on the south side and juxtaposes the upthrown Tyee Intrusion with the Comox and Haslam Formations on the north. Relatively flat-lying remnants of Benson conglomerate are preserved atop the grano-diorite-gneiss in section 76. Clapp (1914) described a similar system of reverse faults west of Nanaimo.

A prominent set of strike faults, paralleling the northeast shore of Ganges Harbor, intersects the coastline 0.25 to 0.5 miles northeast of the government wharf, Ganges. The faults are interpreted to be normal faults with southwest-block down displacements. On the basis of a double repetition of De Courcy Tongue 3 to form the Chain Islands and two sandstone headlands, the faults are interpreted to be normal faults with southwest block down displacement of perhaps several hundreds of feet. These normal faults, in combination with the Ganges Fault Zone, bound a graben of near-vertical and overturned strata which underlies Ganges Harbor and extends northwest to a transverse fault due south of St. Mary Lake.

Traverse Faults

Transverse faults trend N. 33° E. to N. 33° W. Reginald Hill is bounded on the east and west by prominent lineations which trend northeast from Fulford, intersect the coastline through Cusheon Cove and China Cove and offset the basal contact of the Comox Formation. The western most of these two faults passes beneath Lake Weston and juxtaposes the granodioritic Tyee intrusion (on the west side) with Sicker greenstone.

Along the east central coastline of Saltspring Island between Cusheon Cove, Beaver Point and Eleanor Point, there are many exposures which show Comox Formation faulted into contact with the basement. Typical is the coastline between Cusheon Cove and Yeo Point which is beset with shear zones which trend N. 59° to 75° E. and dip 60° to 70° N. The shear zones are about 6 feet wide, spaced at 100-foot intervals, and are breached to form small coastal re-entrants. About 200 feet north of the light house at Beaver Point, a shear zone which cuts Comox sandstone contains a gray quartz vein up to 3 inches thick. Four northwest-trending diagonal faults offset the Comox Formation upper sandstone cuesta in the area between Cusheon Lake and Lake Maxwell. The faults display apparent left-lateral strike separation of the sandstone ridge. However, the offset could result from strike slip, diagonal slip, or northeast block up vertical movement. One of the faults, trending N. 33° W., passes immediately southwest of Roberts Lake and repeats the Haslam Formation to create the anomalously wide section of strike valley. The same fault continues northwest, offsets the Extension-Protection/Haslam contact and repeats the Extension-Protection cuesta under the powerline in lots 26 and 40.

Another major transverse fault extends N. 15° W. from Booth Inlet, along the steep east shore of St. Mary Lake, offsets De Courcy Tongue 3 hogback at the northeast corner of St. Mary Lake, and presumably swings N. 20° W. to intersect the coastline west of Fernwood Point. The southern segment of this fault forms the western boundary of the graben which underlies Ganges Harbor. The De Courcy hogback displays apparent right lateral strike separation which could result from east block-up relative movement. The transverse fault through St. Mary Lake may be the same fault, previously discussed, which offsets the Comox, Haslam, and Extension-Protection Formations, but is offset (right lateral strike separation) across the Ganges Fault Zone.

Many other minor transverse faults exist in the thesis area. A fault which trends N. 27° E., east side up, offsets the De Courcy sandstone cuestas 0.5 miles southeast of Stone Cutters Bay.

ECONOMIC GEOLOGY

Coal

During a century of active mining which ended in the late 1950's, more than 70 million tons of coal were produced from the Nanaimo coal fields (British Columbia Department of Mines and Petroleum Resources, Annual Report, 1969). Richardson (1878) reported thin coals in the middle of the section at Vesuvius Bay and mapped all of the Saltspring Island Cretaceous as "Productive Coal Measures." However, no extensive coal-mining is known to have occurred in the study area. Reports of two tons per day of coal production on the "E. J. Bittancourt place" during the late 1800's could not be confirmed (Hamilton, 1969). The original Jose Bittancourt homestead was in the Vesuvius area (British Columbia Historical Quarterly, 1951, p. 161-202). In 1896, an exploratory hole was drilled 400 feet into vertical strata at the public wharf, Ganges village. No coal was intersected (Annual Report of the Minister of Mines, Province of British Columbia, 1906, p. 205). A seam on the shore platform near Southey Point was worked by owners of the adjacent property. About two feet of overburden were blasted away and perhaps several hundred pounds of coal burned in a fire place (Winter, 1973) (See, also, Appendix I, Measured Section K-L, and PETROLOGY.)

The most promising area for coal prospecting is on the north slope of Mount Maxwell in the middle member of the Comox Formation. The interpreted depositional environment is favorable for coal, and plant debris and coaly laminae are locally abundant. The middle member of the Extension-Protection Formation was also deposited in transitional marine-terrestrial environments and is correlative in stratigraphic position to one of the coal-bearing intervals of the Nanaimo area.

Petroleum

At least from the surface, Cretaceous rocks of the study area show little promise for future petroleum production. Late Cretaceous rocks of the Pacific Northwest, in general, are not regarded as a prime objective section (Braislin and others, 1970). Structural and stratigraphic relationships favorable for entrapment do exist and the dark marine mudstone formations could serve as petroleum source beds. However, reservoir potential in adjacent sandstones seems particularly grim. Even in material from freshly blasted outcrops, porosity is extremely limited; textural immaturity coupled with widespread development of diagenetic matrix and several cementing minerals, contribute to the lack of porosity. Development of prehnite in the Comox Formation could reflect low-grade regional metamorphism as a result of deep burial (six kilometers or more) and slightly elevated temperatures (100° C. or more)(Turner, 1968). Identification of prehnite and laumontite in the Comox Formation adds a new (deep) mineral assemblage to the possible "depth-zoned metamorphic sequence" (laumontite in the Extension-Protection, De Courcy, and Geoffrey Formations; laumontite plus heulandite in the uppermost Gabriola Formation) noted by Stewart and Page (1974). Stratigraphic thicknesses indicate that the Comox Formation was buried at least 8,000 feet (2.7 kilometers) and probably greater than 12,000 feet (3.7 kilometers).

One thin-section contained a few intergranular blebs of black, opaque, nonmetallic material (asphalt?) associated with hematite (sample 2).

Saltwater springs in the Fernwood area are probably fed by connate water which migrates upward along a major fault (Plate 1). A resident of Fernwood, plagued by saltwater seepage through her yard and garden, reported a curious oil stain in her front yard during the summer of 1973 (Winter, 1973).

Construction Materials

The first industry on Saltspring Island was the Salt Spring Stone Company operated by five men during 1859-60. De Courcy sandstone was quarried at Dock Point and the north shore of Booth Bay, sold in Victoria, and used in construction of the Victoria docks and San Francisco Mint Building (British Columbia Historical Quarterly, v. XV, 1951, p. 161-202). De Courcy sandstone is said to harden upon seasoning (Clapp, 1912). Properties which make the stone desirable include:

1) extreme induration;

2) favorable bedding thickness, blocky parting, and rectangular joint pattern;

3) location on the shoreline with ready access to water transport.

Holdfast Pozzolan Limited once operated a pit and roasting plant in the middle Northumberland Formation at Welbury Bay. During 1965, 7,500 tons of pozzolan were produced (British Columbia Department of Mines and Petroleum Resources, Annual Report, 1965, p. 269). Pozzolan is an additive for concrete and is used in the manufacture of building blocks.

As a result of accelerated land development and home construction in recent years, sand and gravel are in great demand. Several pits are located in pockets of glacial drift, and the reader is directed to Regional Geology, Glacial Drift for a description of areas underlain by unconsolidated sand and gravel.

Although not particularly suitable, Haslam Formation mudstone has been widely used as a road metal and fill material.

Tyee Intrusion rock has been mined from a quarry southwest of Cusheon Lake, NW. 1/4, NW. 1/4, Section 78, and used in the construction of breakwaters at the government wharf, Ganges.

Heavy Mineral Sandstone

The Comox Formation beach placer in the upper sandstone member 0.5 miles north of Lake Maxwell contains concentrations of iron-, titanium , and zirconium-bearing minerals (magnetite, ilmenite, hematite, zircon). Although the body is locally at least 10 feet thick and crops out at two localities 1,800 feet apart, it is doubtful that a quantity sufficient for iron ore production exists. However, this occurrence of zircon (1 to 2%) and ilmenite may warrant future investigation by the minerals industry.

GEOLOGIC HISTORY

Sediment Transport Directions

Directions of sediment transport were determined by measuring those primary structures which were formed by current flow and downslope movement of sediment. Where necessary, correction for tectonic tilt was accomplished by rotating channel axes and cross-bedding around the strike line of the master stratification with a stereonet (Potter and Pettijohn, 1963). Directional sole marks and other bedding plane lineations were rotated, on outcrop, to their original orientation utilizing a protractor, Brunton compass, and marking pen (Briggs and Cline, 1969). The orientations of a total of 305 current-formed structures were measured. Means and standard deviations of the 183 unidirectional structures were calculated for 5 stratigraphic units using circular statistical methods presented by Curray (1956).

Comox Formation

A total of 58 directional structures, of which 52 are unidirectional, was measured in the Comox Formation. The mean current-flow direction is N. 19° E. and has a standard deviation of 28° (Figure 58). Measurements were made on conglomerate and sandstone channel axes, trough and planar cross-bed sets, linear-crested

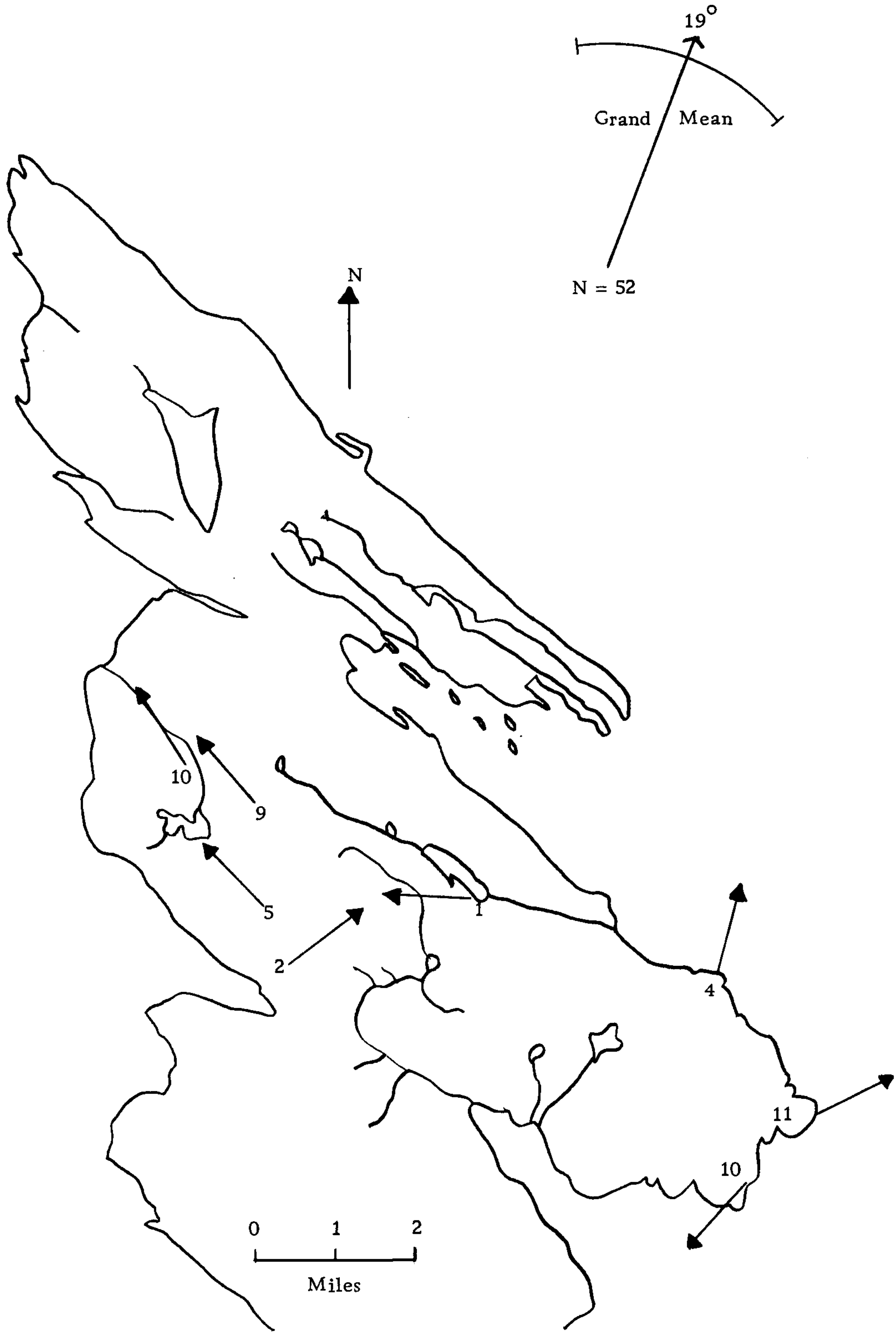


Figure 58. Comox Formation unidirectional paleocurrents. Local means (small arrows), grand mean, and standard deviation (28°) are plotted.

ripple marks, and pebble imbrication.

The overall paleocurrent pattern is radial away from the Tyee Intrusion which is located in the center of the study area. Combined sediment transport directions and lithofacies changes suggest that sediment was derived from the southwest and deposited in non-marine and nearshore marine environments which were flanked from north-west through northeast, to southeast by offshore marine deposition (Figure 63). Divergent current directions at Yeo Point, Beaver Point, and Eleanor Point could have resulted from deposition along a rugged, embayed shoreline during initial transgression of the Late Cretaceous seaway.

Extension-Protection and Lower Cedar District Formations

A total of 45 directional structures, of which 29 are unidirectional, was measured in the Extension-Protection and lower Cedar District Formations. The mean current-flow direction is N. 79° W. and shows a rather large standard deviation of 54° (Figure 59). Measurements were made from sandstone and conglomerate channel axes, cross-bedding, cross-lamination, flute casts, groove casts, parting lineation, pebble imbrication and sand waves. Cross-laminae and penecontemporaneous folds and thrust faults which are only exposed in two-dimensions in the lower Cedar District (Measured

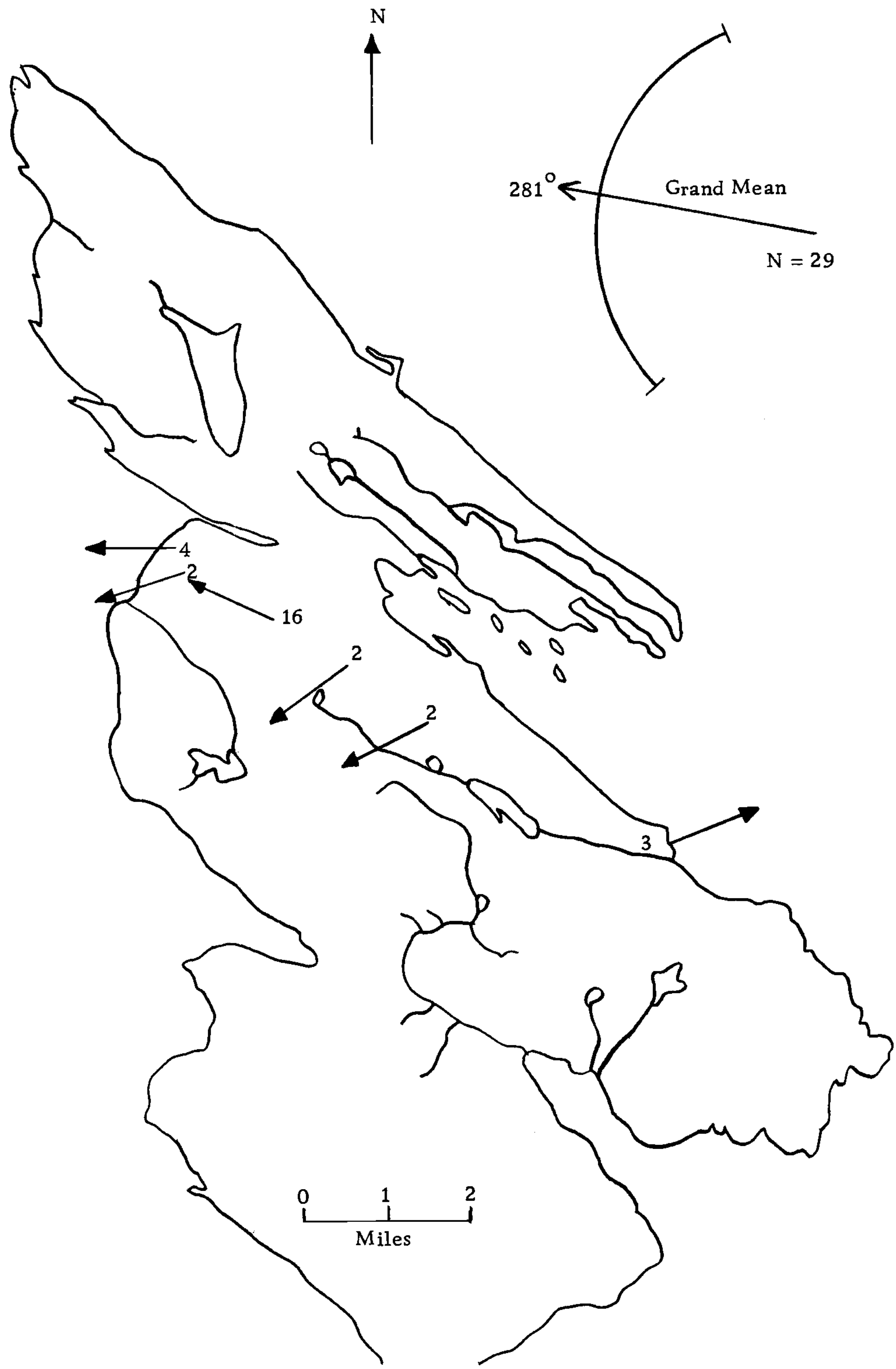


Figure 59. Extension-Protection Formation unidirectional paleocurrents. Local means (small arrows), grand mean, and standard deviation (54°) are plotted.

Section A-B), record current flow and paleoslope to the east in the lower part of the section and to the west in the upper part. Most of the cross-laminae seen in the Extension-Protection middle member along Old Divide Road are inclined to the southeast along strike.

Paleogeographic reconstruction of the Extension-Protection Formation is hindered by the small number of paleocurrent measurements and their large variance and is further complicated by the thinning of the formation to the southeast, diametrically opposed to the mean transport direction. However, the Ganges Harbor member apparently does thin to the northwest.

Middle and Upper Cedar District Formation

A total of 27 current-formed structures was measured in the middle and upper Cedar District Formation. The 17 unidirectional structures yield a mean of N. 88^{o} W. and standard deviation of 45^{o} (Figure 60). Flute casts, groove casts, trough cross-lamination (crescentic ripple marks and rib-and-furrow), parting lineation, and linear-crested ripple marks were measured. At many localities (Vesuvius Bay, Unit 1; coastline northwest of Fernwood; south side of Welbury Point) innumerable siltstone and fine-grained sandstone laminae display cross-lamination with foresets which are invariably inclined to the northwest as seen in two-dimensions. In addition,

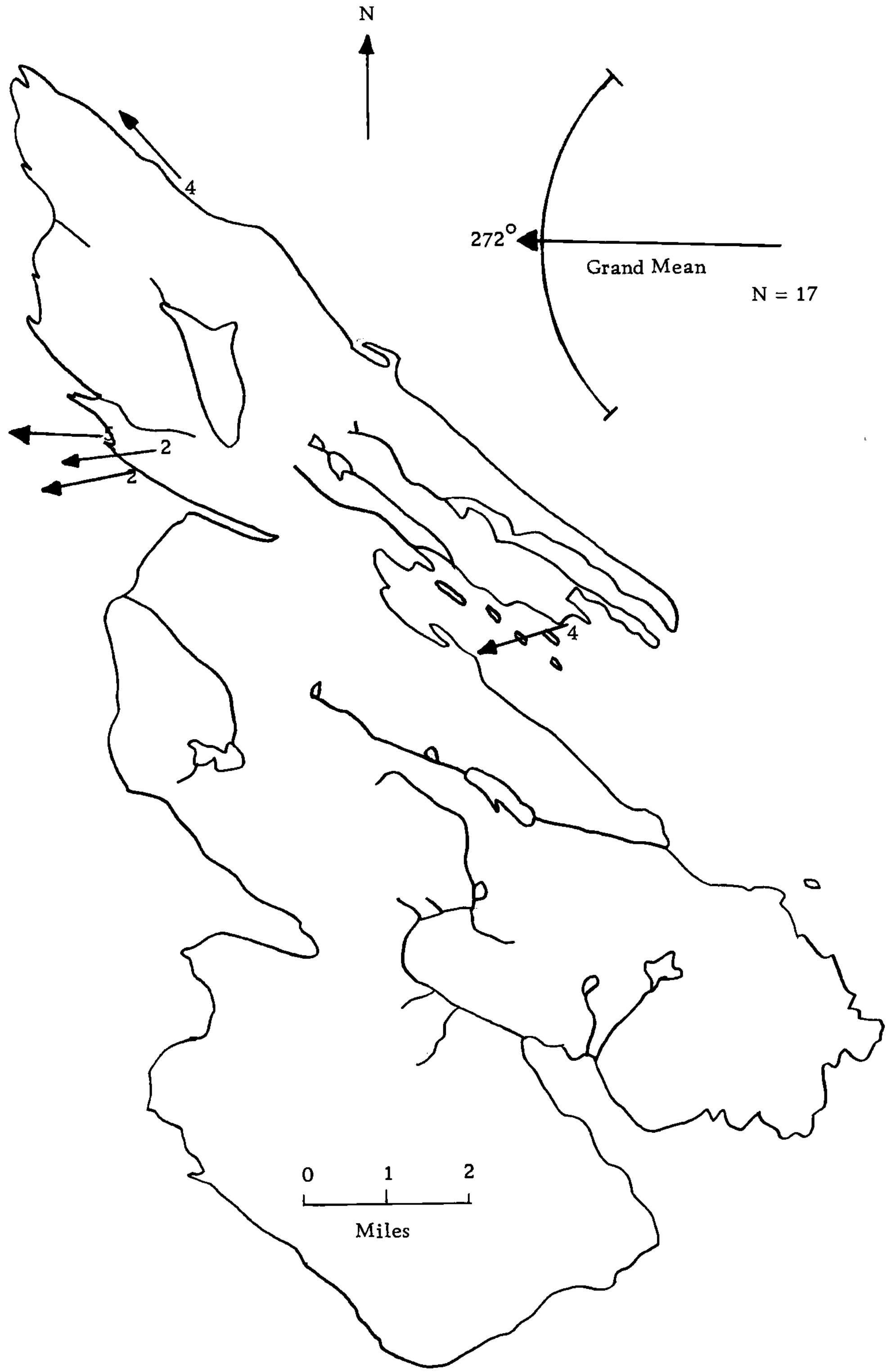


Figure 60. Summary of Cedar District Formation unidirectional paleocurrents. Local means (small arrows), grand mean, and standard deviation (45°) are plotted.

small penecontemporaneous folds are commonly overturned to the northwest or west.

Because no major channel axes were measured, it is not known whether the measured structures were formed by currents which delivered sediment to the basin or by tidal or other bottom currents which flowed parallel to the shoreline and reworked sediment deposited by other (turbidity?) currents.

De Courcy Formation

A total of 135 directional structures, of which 55 are unidirectional, was measured in the De Courcy Formation. The grand mean current direction is N. 77° W. with a standard deviation of 27° (Figure 61). Flute casts, groove casts, prod casts, bounce casts, current crescent casts, trough cross-bedding, trough cross-lamination, oriented plant fragments, parting lineation, frondescent marks, and sand waves were measured. The data are biased in favor of two localities where 43 of the unidirectional structures were measured. Many more structures, primarily groove casts, could have been measured at these two localities, but an attempt was made to get representative samples from as many bedding planes as possible. Although most of the directional structures are sole marks, measurements from trough cross-bedding, cross-lamination, and sand waves give comparable directions.

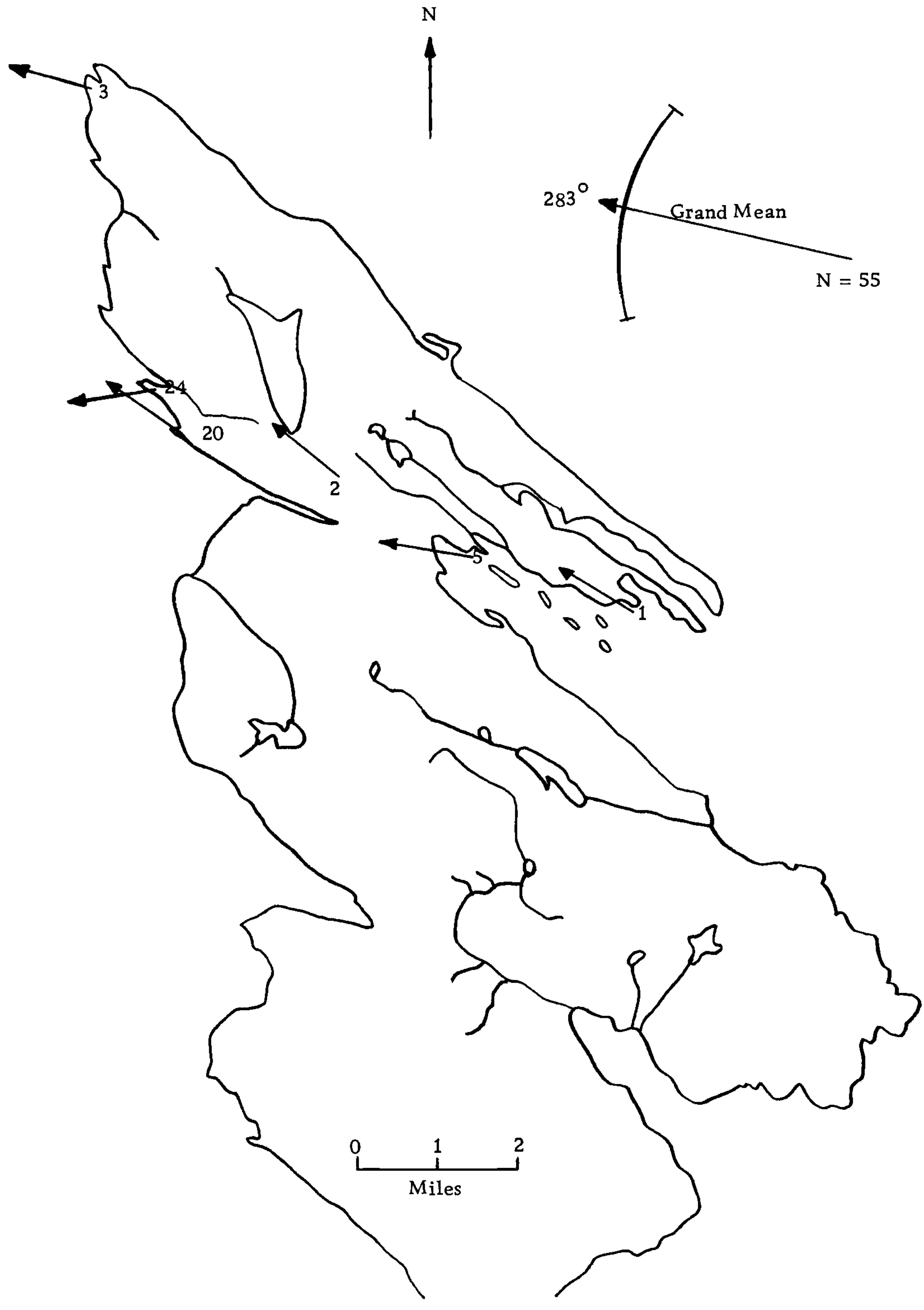


Figure 61. Summary of De Courcy Formation unidirectional paleocurrents. Local means (small arrows), grand mean, and standard deviation (27°) are plotted.

Upper De Courcy sandstone bodies, as shown by their map distribution (Plate 1) and correlation across the Kulleet Syncline (Figure 22), may have an elongate geometry (elongation parallel to transport directions) and widths of a few miles and less.

Northumberland and Geoffrey Formations

A total of 40 directional structures, of which 30 are unidirectional, was measured in the Northumberland and Geoffrey Formations. However, the coverage is rather poor; 22 were measured at a single locality in the upper Northumberland Formation. The grand mean current direction is N. 25° E. with a standard deviation of 21° (Figure 62). Cross-lamination, trough cross-bedding, groove casts, flute casts, parting lineation, conglomerate channel axes, and pebble imbrication were measured.

Three small (2-inch amplitude) penecontemporaneous folds in the upper Geoffrey Formation at Nose Point are overturned to the north and suggest a paleoslope in that direction. The combination of paleocurrents, the fining and thinning of the conglomerates, and the lateral change in character of the contact with the Northumberland Formation (see Northumberland Formation, Contact Relationships), strongly support derivation of the Geoffrey Formation from a source area located to the south, southwest, or southeast. To the north of the study area on Thetis and Kuper Islands, Geoffrey paleocurrents

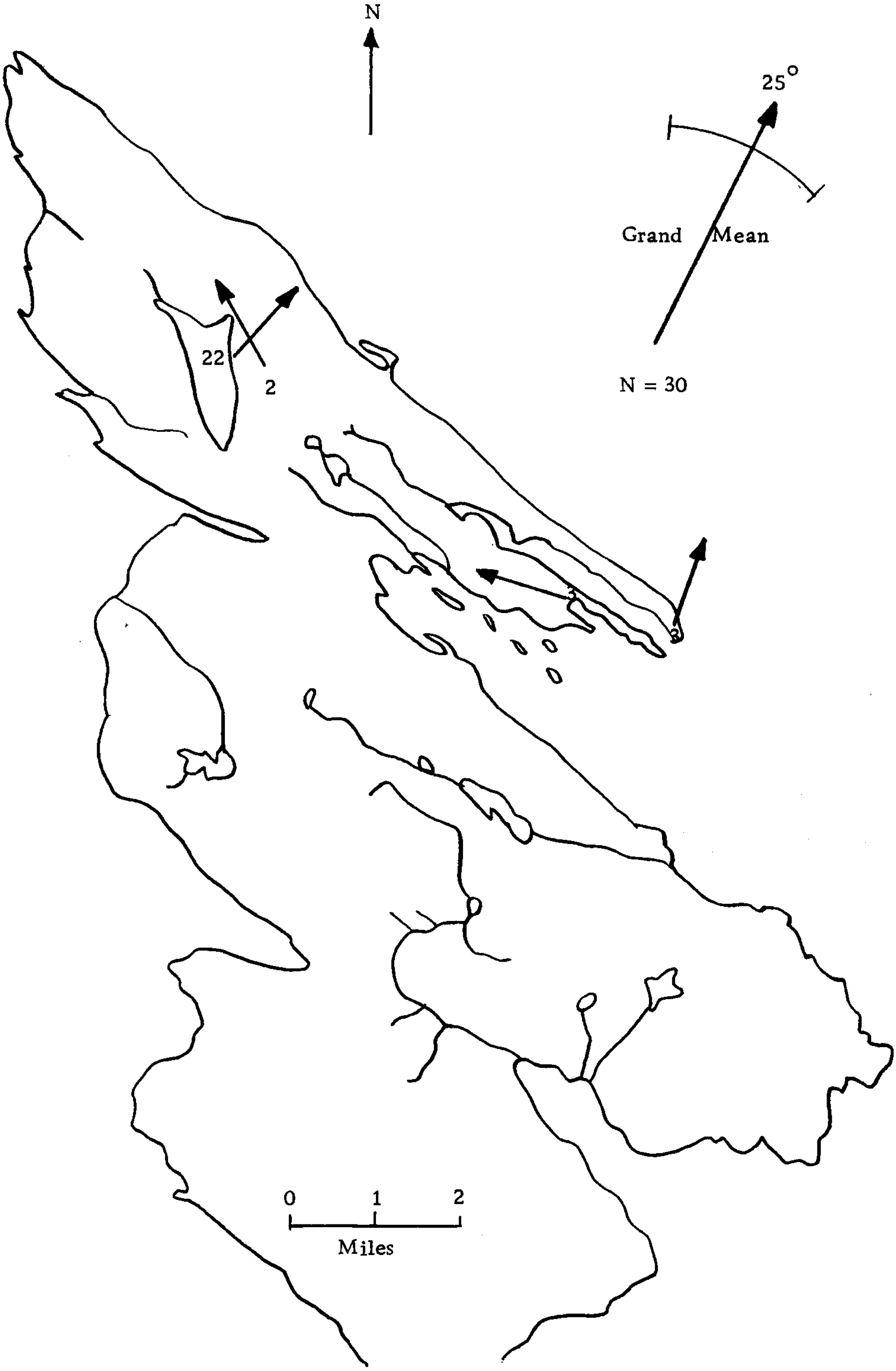


Figure 62. Northumberland and Geoffrey Formation unidirectional paleocurrents. Local means (small arrows), grand mean, and standard deviation (21°) are plotted.

indicate transport of sediment to the north (Simmons, 1973); on North and South Pender Islands, southeast of Saltspring Island, transport was to the southeast (Hudson, 1974). From these data it is possible to interpret a radial paleocurrent dispersal pattern emanating from Saanich Peninsula on southern Vancouver Island.

Provenance and Source Areas

Mineralogy of sandstones and lithology of conglomerate clasts in Cretaceous rocks of the study area are compatible with derivation from the Paleozoic-Mesozoic basement complex of southern Vancouver Island and the San Juan Islands of Washington State. Additionally, sediment transport directions and facies changes generally indicate a southern source, although the De Courcy paleocurrents flowed toward the west. However, the vertical stratigraphic sequence shows definite lithic and mineralogic changes in the Nanaimo Group sediments. These changes are probably a result of changes in provenance.

The Comox Formation was derived from a nearby low to medium grade metamorphic and intermediate to basic igneous source of high relief. Many of the conglomerate clasts are analogous to lithologies in the late Paleozoic Sicker Group - meta-andesite, green-schist, diorite, chert, dacite porphyry - and Tyee Intrusion - granodiorite, gneissic granodiorite, aplite. A pebbly sandstone near

Eleanor Point contains abundant clasts of the distinctive grayish green dacite porphyry which crops out near Beaver Point (see Regional Geology, Sicker Group). The minerals epidote, actinolite, chlorite, zoisite, clinozoisite, green garnet (grossularite?), and polycrystalline and undulatory quartz are indicative of a low-grade metamorphic terrane. Ilmenite, leucoxene, magnetite, augite, hypersthene, and possible chromite suggest a basic igneous contribution. Microcline could have been derived from gneiss or silicic plutonic rocks. Microcline was found in a schist fragment and quartzite pebble from the Comox Formation. However, microcline is very rare on Vancouver Island (Carson, 1973). Survival of angular augite and actinolite suggest proximity to the source area. Euhedral zircons in Comox beach placers suggest a first cycle parentage.

Probable Comox source rocks are the Sicker Group and early Mesozoic metamorphic equivalents, the Wark Diorite and Colquitz gneiss which underlie a large part of southern Vancouver Island (Muller, 1975). The Sicker Group contains abundant epidote, actinolite, hornblende, chlorite, biotite, leucoxene, magnetite, augite, andesine to labradorite, and albite (Fyles, 1955). The Colquitz gneiss is a gneissic quartz diorite which contains hornblende, biotite, chlorite, epidote and strained quartz (Muller, 1975). Zircon probably occurs widely in the Sicker Group (Muller, 1974).

The Extension-Protection and particularly the De Courcy and Geoffrey Formations record a decreased contribution of sediment from metamorphic and basic igneous rocks and an increased contribution from an intermediate to silicic intrusive and extrusive igneous provenance. An upward increase in the proportion of potassic feldspars is indicated (Comox 4.2%; Extension-Protection 8.6%; Cedar District-De Courcy 10.3%; Geoffrey 10.6%; see Appendix IV).

Many possible sources exist for the clasts of "radiolarian chert" which are very abundant in the Extension-Protection Formation: Jurassic Bonanza Volcanics contain brecciated and foliated pyritic cherts with quartz veins (Muller, 1975); Permian bedded cherts with radiolarian ghosts are abundant in the San Juan Islands and North Cascades (Danner, 1970); gray, fractured cherts cemented by quartz veins are abundant on Orcas Island and the Leach River schist contains abundant pebbles of "Orcas Chert" (McLellan, 1927). Clapp (1912) recognized Sicker chert as a major component of the Extension Formation.

De Courcy and Cedar District paleocurrents indicate sediment transport to the west and consequently a possible eastern or southeastern source. De Courcy sediments differ from those of the Geoffrey Formation only in the lower content of volcanic rock fragments; an intermediate to acid igneous source of high relief which had undergone mainly mechanical weathering, is indicated. The abundant silicic to intermediate volcanic debris and black phyllite in the Geoffrey Formation could have been derived from the Bonanza Volcanics, an early Mesozoic andesitic island arc assemblage which underlies a major part of the Victoria map area (Muller, 1975). No other source on Vancouver Island of relatively fresh (glass exists in some volcanic rock fragments in carbonate-cemented concretions), vitrophyric silicic volcanic rock fragments is known. The Bonanza Volcanics are less metamorphosed than the Sicker Group and consists of andesites, reddish to greenish dacites, and vitrophyric rhyo-dacites. Phenocrysts include hornblende, oligoclase, and andesine.

The Saanich Granodiorite, one of the early to middle Jurassic Island Intrusions, underlies much of Saanich Peninsula and may have been a major source for the upper Nanaimo Group. The Saanich Granodiorite contains quartz, biotite, andesine to oligoclase, microperthitic orthoclase, myrmekite, apatite, chlorite, epidote, sphene and prehnite (Clapp, 1912; Clapp and Cook, 1917; Carson, 1973; Muller, 1975).

The source of quartzite clasts - originally supermature quartz sandstones - in the Comox, Extension-Protection, and Geoffrey Formations is enigmatic. Perhaps the clasts are recycled from older conglomerates of the San Juan Islands. However, "quartzite" is reported to occur in the Triassic Karmutsen Formation (Carson, 1973, p. 4) and Muller (1975, p. 24) reports much "quartz sand" in limestones associated with the basaltic Karmutsen volcanics.

History

Deposition of Late Cretaceous sediments of the thesis area occurred in a rapidly subsiding marine basin off the east coast of southern Vancouver Island. The basin developed possibly on a major geosuture near the southeast margin of an early Mesozoic island arc complex which had been accreted to the continental margin during the Jurassic (Monger and others, 1972). To the northeast of the Nanaimo Basin, plutons in the core of the southern Coast Crystalline Belt of the present mainland of British Columbia had been, were being, and would be emplaced (McTaggart, 1970).

Deposition of Comox and Haslam sediments commenced during the Santonian Age as the Late Cretaceous sea transgressed a very rugged terrain. Consequently, detritus was rapidly eroded and deposited resulting in preservation of unstable mineral and rock fragments. Comox sands and gravels were shed northward as alluvial fans or fan deltas which emanated from a headland of Paleozoic rocks. At the northwest margin of the clastic wedge local beach placers, rich in mafic minerals, formed in response to storm wave activity. Farther basinward, marine mudstones of the

Haslam Formation were deposited directly upon metamorphic basement (Figure 63).

To the southeast, rapid transgression in the Yeo Point to Eleanor Point areas along a cliffed coastline resulted in deposition of well sorted littoral sands and gravels in a seaway of normal or near normal salinity. Basin subsidence eventually resulted in complete inundation and deposition of Haslam marine mud over the entire thesis area. The end of this first cycle of sedimentation was marked by uplift and creation of an eroded surface upon which basal conglomerate of the Extension-Protection Formation was deposited.

The Extension-Protection and lower to middle Cedar District Formations record two successive transgressive cycles which were initiated by deposition of gravels and characterized by a vertical progression from nonmarine and nearshore marine to offshore marine deposition. The first upward-fining transgressive cycle consists of the lower conglomerate and middle member of the Extension-Protection Formation. The second transgressive sequence consists of the upper conglomerate member and lower to middle Cedar District Formation. The coarseness of sediments is indicative of a nearby uplifted source which was drained by high energy streams. The Extension-Protection upper conglomerate member was probably deposited as a basin-margin fan. To the southeast of this coarse gravel wedge, offshore marine mud deposition was

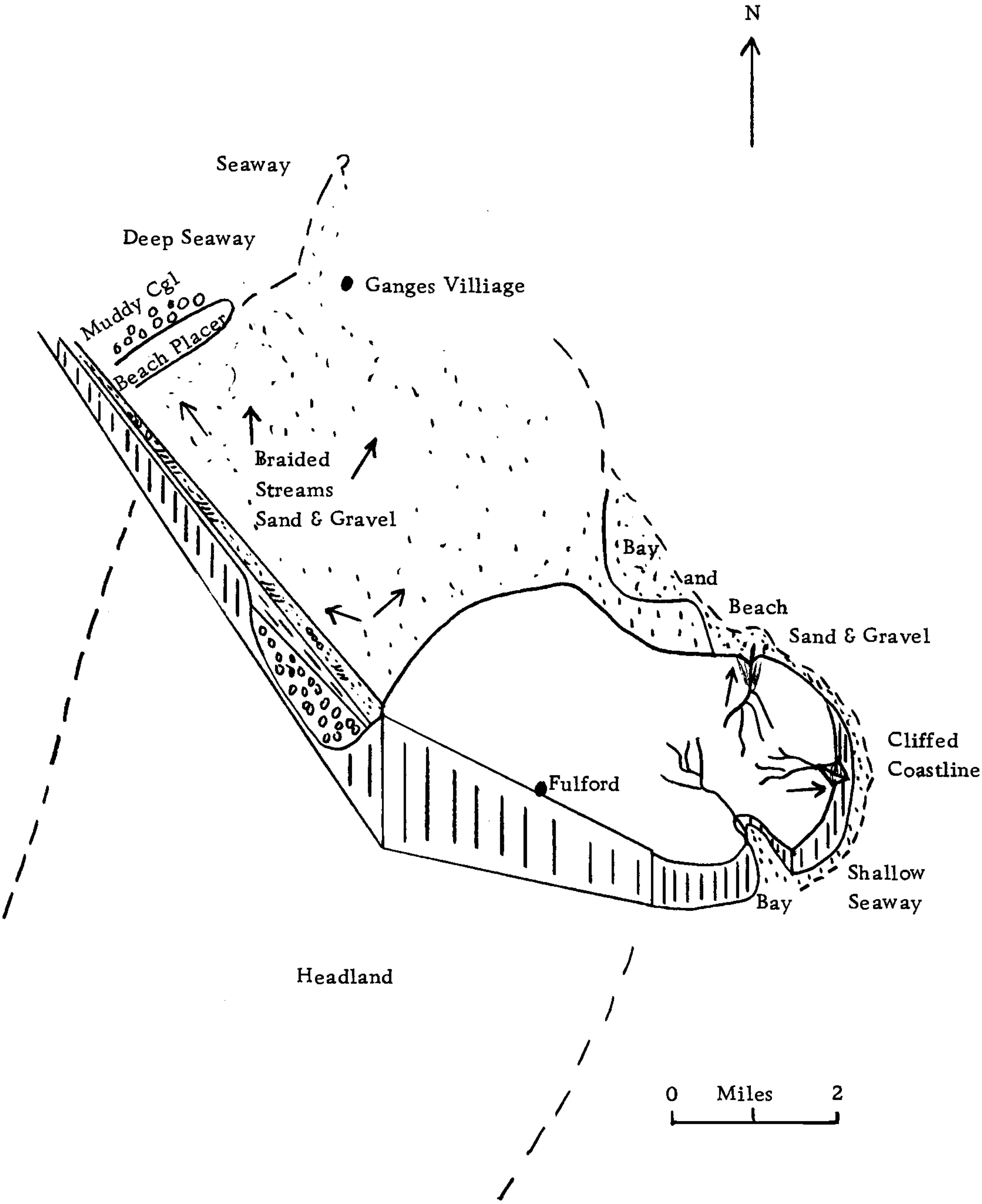


Figure 63. Possible paleogeographic reconstruction of study area during late Comox time (late Santonian - early Campanian).

periodically interrupted by turbulent influxes of sand and silt which created the repeated graded bedding in the lower Cedar District Formation. Again, continued or perhaps accelerated basin subsidence inundated the clastic wedges and resulted in deposition of marine mud, the middle Cedar District member, throughout the thesis area.

The upper Nanaimo Group of Saltspring Island, middle Cedar District to Spray Formations, records a series of at least four major incursions of coarse clastics into a moderately deep marine basin. De Courcy sandstone bodies were derived from an intermediate to silicic igneous or possibly low to medium grade metamorphic source located to the southeast or east. Deposited as delta-front sands, the De Courcy bodies locally grade upward into channelized fluvial-marine pebble conglomerates. Basinward progradation of delta-front sands resulted when the rate of sediment delivery exceeded redistribution by marine waves and currents. Deltas were characterized by steep slopes as a result of rapid deposition by high gradient fluvial systems and outbuilding into fairly deep water. (Water depths were equal to or slightly greater than the present Strait of Georgia (Sliter, 1973).) Slumping on steep, unstable delta-front slopes generated subaqueous debris flows, fluidized sediment flows and turbidity flows such as those preserved in the upper Cedar District Formation at Vesuvius Bay. The

De Courcy Southey Point member (Kd_3), laterally equivalent to the upper Cedar District Formation, records a progradational sequence from a delta-front slope facies to a coal-bearing deltaic plain facies.

The Northumberland Formation marks a return to prodelta mud deposition over the entire thesis area and the beginning of the last complete sedimentation cycle preserved in the thesis area, the Northumberland-Geoffrey cycle. The Geoffrey delta prograded toward the north across the thesis area and was constructed of sediment derived from a southern source rich in intermediate to silicic volcanic rocks. This cycle is similar to those of the Cedar District and De Courcy Formations in that it was initiated by an upward-coarsening prodelta to delta-front transition. However, the Geoffrey delta differs from those of the De Courcy Formation in that the fluvial phase is well developed; high gradient stream channels extended farther basinward and deposited gravels the entire length of the study area. A return to delta-front sand and finally prodelta mud deposition is marked by the upper sandstone member of the Geoffrey and the Spray Formation, respectively. Intertonguing of the Geoffrey Formation delta-front sands with Northumberland and Spray Formation delta-front to prodelta thinly bedded sand mud sequences, could have resulted from fluctuations in sediment supply, shifting of channel mouths, changes in rate of subsidence, or sealevel changes.

Post-Cretaceous basement block movements resulted in a northwest-trending structural grain. Folding is probably related to movements along major faults. Two or more phases of faulting may have occurred as shown by possible fault offset of pre-existing faults. The major structure of northeast-tilted fault blocks bounded by normal faults is generally regarded as a result of a tensional stress system. The zone of reverse faults and overturned strata along the southwest shore of Ganges Harbor suggests differential uplift of the Tyee Intrusion block. The present regional stress system is one of north to south or northeast to southwest compression (Crosson, 1972; Mayers and Bennett, 1973).

Later, Pleistocene glaciation resulted in excavation of non-resistant mudstone formations and fractured fault zones. Thick deposits of glacial drift accumulated in low-lying areas including bays and mountain flanks. Post-glacial lakes filled scoured fault zones and depressions in mudstone strike valleys.

The most recent geologic events include a few minor landslides (Geoffrey sandstone at the south end of St. Mary Lake, and Extension-Protection Conglomerate west of Mount Belcher) and slumping of the Northumberland Formation along Trincomali Channel and Haslam Formation along Fulford Harbor.

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APPENDICES

APPENDIX I

MEASURED SECTIONS

Measured Section A-B, Cedar District Formation, Extension-Protection Formation, Haslam Formation, and Comox Formation.

Section A-B was measured along the east central coastline of Saltspring Island near the mouth of Cusheon Creek. The west-northwest to east-west-trending valley of Cusheon Creek is a strike valley developed on the nonresistant Haslam Formation. The shear south valley wall consists of slightly foliated granodioritic Tyee Intrusion which is locally overlain by thin remnants of the Comox Formation. The linear ridge of the north valley wall and cliffed headland immediately north of the mouth of Cusheon Creek are topographic expressions of the resistant Extension-Protection Formation. The latter is overlain by the lower member of the Cedar District Formation which forms the ribbed shore platforms, low seacliffs, and sandy pocket beaches extending for 0.25 miles north of the Extension-Protection headland. The lower Cedar District Formation, is a marine tubidite sequence, and is laterally correlative to Extension-Protection Formation sandstone and conglomerate on Mount Belcher and Mount Erskine to the northwest.

Terminal point B: assumed to be top of lower Cedar District Formation; is 2,000 feet north of mouth of Cusheon Creek at north end of public beach in northeast 1/4, Section 76, Saltspring Island.

Contact at B; lower member of Cedar District Formation and Ganges Harbor member of Extension-Protection Formation; covered, is placed at base of a sequence of very thick-bedded, coarse-grained sandstones.

Interval (feet)	Description

Lower member of Cedar District Formation (thickness = 1,056 feet). Unit description: repetitively interbedded sandstone, siltstone, and mudstone; forms high-tide shore platforms and low seacliffs.

Sandstone and siltstone: resistant thin rib-formers; light olive gray (5Y 6/1) to medium dark gray (N4), weathered; light gray (N7), fresh; beds range from 0.5 to 48 inches thick, but are mostly thin beds 2 to 12 inches thick; individual beds are thinly laminated (about 15 to 18 per inch) and normally graded from sandstone to siltstone or argillaceous siltstone; cross-lamination, sinusoidal ripple (undulating) lamination (wavelength 2 to 8 inches, amplitude 0.25 to 0.5 inches), contorted lamination, injection structures, and mudstone rip-ups are locally abundant; fine- to very fine-grained sandstone to argillaceous siltstone; moderately sorted; subangular; quartz, feldspar, black grains, muscovite; noncalcareous. Upper contacts are mostly sharp and planar, although sharp undulating, sharp truncated, and gradational contacts are present. Lower contacts are invariably sharp and dominantly planar, although local relief is due to flame structure, load and flute casts, and broad cut-and-fill.

Mudstone interbeds: nonresistant; medium gray (N5) to dark gray (N3), fresh and weathered; weathers into chips 1 by 1.5 inches; laminae to thin beds (0.25 to 24 inches), mostly thin beds; individual beds are thinly laminated (28 per inch) and locally vary in thickness along strike because of loading and truncation. Locally present are sandy laminae, sand-filled organic burrows about 0.25 to 0.5 inches diameter, and rare Inoceramus valves and fragments.

1056-692	Nonresistant interval covered by white shell beach.
692-652	Mudstone as in unit description contains calcareous mudstone interbeds and minor siltstone laminae. Calcareous mudstone: light gray (N7); stand out as resistant ribs 0.5 to 1 inch thick which are spaced at intervals of 3 to 12 inches.

Measured Section A-B, Cedar District, Extension-Protection, Haslam, and Comox Formation (cont.).

Interval (feet)	Description
	Contact sharp, planar.
652-340	Repetitively interbedded sandstone-siltstone and mudstone sequence as in unit description; consists of about 35 percent sandstone and siltstone. Sandstone-siltstone: range from 0.5 to 19 inches thick and average about 3 inches; most beds have thinly laminated bases, sharp planar tops and bottoms, and exhibit cross-lamination and/or contorted lamination in their upper third. Mudstone: as in unit description; range from 1 to 24 inches thick and average about 6 inches. A few calcareous beds to 4 inches thick are present. Attitude is N. 87° W., 82° N.
	At 509, ball-and-pillow structure: disconnected very fine-grained sandstone pillows, 16 to 21 inches long, 6 to 8 inches thick, lie in a mudstone matrix which bends around them; sandstone bodies show indistinct internal contorted lamination, have sharp arcuate convex bases and gently undulating to slightly concave tops.
340-260.5	Covered by sand beach.
260.5-213	Repetitively interbedded sandstone-siltstone and mudstone sequence as in unit description: consists of about 65 percent sandstone and siltstone. Sandstone-siltstone: beds range from 0.5 to 6 inches thick and average about 2 inches. Mudstone: range from 0.25 to 5 inches thick and average about 1 inch; commonly contain silty laminae and organic burrows on bedding planes.
	Contact sharp, planar.
213-209	Sandstone: resistant rib-former; light olive gray (5Y 6/1), weathered; light gray (N7), fresh; laminated (5 to 7 per inch); medium- to fine-grained; moderately sorted; subangular to angular; quartz, feldspar, biotite, muscovite, black grains; noncalcareous. 50 feet along strike to the east, the bed has thickened to 61 inches. A wavy sandstone dike 1 to 3 inches thick and 14 inches long extends from the top of this bed and cuts thin units above. Basal 6 inches contains flat mud rip-ups with maximum dimension of 2 inches. Sole possesses large (4 to 8 inches diameter) load casts. Lith sample WBH-81.
	Contact sharp, load casts with 5 inches relief.
209-138	Repetitively interbedded sandstone-siltstone and mudstone sequence as in unit description: consists of about 70 percent sandstone and siltstone.

Measured Section A-B, Cedar District, Extension-Protection, Haslam, and Comox Formations (cont.).

Interval (feet)	Description
	Sandstone-siltstone: range from 0.5 to 24 inches thick, average thickness is noticeably greater than interval 652-213; most are normally graded (71 percent in interval 148-138) and contain Bouma sequences of sedimentary structures, especially plane parallel lamination in lower halves and cross-lamination and/or contorted laminae in upper third. Most beds are parallel-sided and laterally continuous in outcrop, but a few of the thicker beds possess horizontal joints, intraformational mudstone clasts to 3 inches dimension, and convex lower surfaces which truncate subjacent beds.
	Mudstone: as in unit description; beds range from 0.5 to 15 inches thick and average about 3 inches. They locally vary in thickness along strike as a result of load deformation and truncation.
	Attitude is N. 84° W., 67° N.

Interval 148-138 is detailed below:

z. Mudstone, 0.5 inches. Contact gradational.

y. Siltstone, 1.0 inches; thinly laminated. Contact sharp, planar.

x. Mudstone, 12.4 inches; with very thin, laterally persistent siltstone laminae. Contact gradational and gently undulating.

w. Very fine-grained sandstone to siltstone, 1.0 inches; normally graded, upper part contains cross-lamination and sinusoidal (undulating) ripple lamination. Contact sharp, planar.

v. Mudstone, 5.8 inches. Contact gradational.

u. Siltstone, 1.5 inches; normally graded, Bouma C-E sequence. Contact sharp, planar.

t. Mudstone, 4.2 inches. Contact sharp, planar.

s. Very fine-grained sandstone to siltstone, 5.3 inches; normally graded, structureless. Contact sharp, planar.

r. Medium-grained sandstone to siltstone, 10.2 inches; normally graded Bouma B-E sequence. Contact sharp, planar.

q. Very fine-grained sandstone to siltstone, 3.3 inches; Bouma A-E sequence, sinusoidal ripple lamination in division C (wavelength 2-3 inches, amplitude 0.25 inches). Contact sharp, planar.

p. Very fine-grained sandstone to siltstone, 3.5 inches; Bouma A-E sequence, cross-lamination indicates paleocurrent to east.

Contact sharp, planar.

o. Mudstone, 15.0 inches. Contact gradational.

Measured Section A-B, Cedar District, Extension-Protection, Haslam, and Comox Formations (cont.).

Interval (feet)	Description
	n. Very fine-grained sandstone to siltstone, 18.8 inches; normally graded, Bouma B-C sequence. Contact sharp, planar.
	m. Mudstone, 1.7 inches. Contact gradational.
	l. Very fine-grained sandstone to siltstone, 3.4 inches; normally graded, with sinusoidal ripple lamination (wavelength 3 inches, amplitude 0.5 inches), bed disturbed by soft sediment overfolding and faulting which indicate paleoslope inclined to east. Contact sharp, planar.
	k. Mudstone, 5.7 inches. Contact gradational.
	j. Fine-grained sandstone to siltstone, 14.0 inches; normally graded, Bouma B-E sequence, cross-lamination indicates paleocurrent to east. Contact sharp, planar.
	i. Mudstone, 3.3 inches. Contact sharp, gently undulating.
	h. Siltstone, 1.5 inches; structureless. Contact sharp, planar.
	g. Very fine-grained sandstone to argillaceous siltstone, 1.6 inches; normally graded, thinly laminated 28 per inch. Contact covered.
	f. Mudstone, 1.1 inches. Contact sharp, gently undulating.
	e. Very fine-grained sandstone to siltstone, 2.8 inches; normally graded, structureless except for indistinct cross-lamination. Contact sharp, planar.
	d. Mudstone, 0.5 inches. Contact gradational.
	c. Very fine-grained sandstone to siltstone, 2.5 inches; normally graded, Bouma C-E sequence, cross-lamination indicates paleocurrent toward the east. Contact sharp, planar.
	b. Mudstone, 2.9 inches. Contact gradational.
	a. Very fine-grained sandstone to siltstone, 0.9 inches; normally graded, Bouma B-C sequence. Contact sharp, planar.
138-0	Covered by beach sand. Float on low, brushy seacliff in this interval is silty mudstone.
	At 0 offset 100 feet N. 75° W.

Contact: Cedar District Formation, lower member, and Extension-Protection Formation; covered.

Extension-Protection Formation (thickness = 181 feet).

Interval (feet)	Description
181-173	Sandstone: resistant; medium dark gray (N4) to medium light gray (N6), weathered; laminated to very thin-bedded; thinly platy to flaggy parting; fine- to medium-grained; moderately sorted; subangular to subrounded; slightly calcareous; quartz, feldspar, lithic grains.
	Contact sharp, planar.

Measured Section A-B, Cedar District, Extension-Protection, Haslam, and Comox Formations (cont.).

Interval (feet)	Description
173-169.5	Sandstone: brownish gray (5YR 4/1), weathered; structureless; fine- to medium-grained; moderately sorted; subangular; noncalcareous; quartz, chert, limonitic grains; lower 6 inches contains fine to medium, subrounded chert pebbles in matrix support.
	Contact sharp, scoured with 3 inches relief over 3 feet of contact.
169.5-167.5	Siltstone: nonresistant; medium dark gray (N4) to light brown (5YR 5/6), weathered; weathers out as rusty plates 2 by 3 by 0.5 inches thick.
	Contact sharp, gently undulating.
167.5-166	Pebbly sandstone: brownish gray (5YR 4/1), weathered; structureless; fine- to medium-grained; moderately sorted; subangular; quartz, chert, limonitic grains; noncalcareous; contains fine to medium chert pebbles, subrounded, matrix-supported.
	Contact sharp, scoured with 6 inches relief, 2 feet wavelength.
	At 166 offset 200 feet N. 75° W.
166-159.5	Interlaminated sandstone and silty mudstone: nonresistant. Sandstone laminae: olive gray (5Y 5/1), weathered; indistinctly cross-laminated; very fine-grained; well sorted. Silty mudstone laminae: medium gray (N4); calcareous. Overall, the unit is laminated (2 to 12 per inch).
159.5-154.5	Covered by beach sand.
154.5-146	Interlaminated sandstone and silty mudstone as at 159.5-166.
	Contact sharp, gently undulating.
146-139	Sandstone: olive gray (5Y 5/1), weathered; thin- to thick-bedded (8 to 36 inches); very fine- to fine-grained; moderately sorted; angular; quartz, chert, feldspar, rock fragments; noncalcareous; basal 2.5 feet contain mud rip-ups to 1.5 inches dimension and indistinct cross-bedding.
	Lith sample WBH-82 at 140.
139-137	Sandstone: olive gray (5Y 5/1), weathered; laminated (5 per inch); very fine-grained; well sorted; subangular to subrounded; quartz, chert, feldspar; noncalcareous.
	Contact sharp, planar.
137-134	Sandstone: olive gray (5Y 5/1), weathered; structureless; fine-grained; well sorted; subangular; quartz, chert, feldspar; noncalcareous.
	Contact gradational over 6 inches.

Measured Section A-B, Cedar District, Extension-Protection, Haslam, and Comox Formation (cont.).

Interval (feet)	Description
134-131.5	Intraformational mudclast conglomerate: medium dark gray (N4), weathered; unit is about 80 percent flat mud rip-ups to 2 inches long; they are flat and oriented subparallel to bedding; matrix-supported; a few fine to medium chert pebbles are present; matrix is fine- to medium-grained sandstone. Attitude is N. 75° W., 65° N.
	Contact gradational over 2 inches.
131.5-128.5	Sandstone: olive gray (5Y 5/1), weathered; very thin-bedded (10 per foot); tendency for flaggy parting; fine- to medium-grained; moderately to well sorted; angular to subrounded; predominantly quartz with minor feldspar and biotite; noncalcareous; abundant mud rip-ups, 0.25 by 0.75 inches oriented subparallel to bedding.
	Contact covered.
128.5-113.5	Covered by sand and sandstone blocks.
	At 113.5 offset 30 feet N. 75° W.
113.5-97.5	Sandstone sequence: weakly ribbed backshore; grayish olive (10Y 4/2), weathered; consists of repetitively interbedded coarse- and fine-grained sandstones. Sandstone: resistant ribs; thin- to thick-bedded (1.5 to 3 feet), individually indistinctly laminated to structureless; fine- to coarse-grained; poorly sorted; subangular to rounded; quartz, feldspar, chert; noncalcareous; contains some matrix-supported very fine quartz pebbles and abundant mud and silt rip-ups to 2 inches dimension. Sandstone interbeds: nonresistant; thin-bedded (2 to 7 inches), individual beds are laminated (5 per inch); very fine- to fine-grained; well sorted; noncalcareous. Contacts are sharp and planar.
	Contact covered by sandstone blocks.
97.5-94	Conglomerate and sandstone sequence: prominent rib-former on foreshore; thin-bedded (6 to 14 inches). Conglomerate: brownish gray (5YR 4/1), overall aspect; fine to coarse pebbles; grain-supported; subrounded to rounded; predominantly chert, minor white quartz. Sandstone: medium light gray (N6), weathered; structureless; fine-grained; moderately sorted; angular to subangular; quartz, chert, feldspar, limonitic grains.
	Sequence: 10 in. conglomerate Contact planar to gently undulating 14 in. sandstone Contact irregular with up to 4 in. relief, is lined with siltstone clasts to 10 in. long

Measured Section A-B, Cedar District, Extension-Protection, Haslam, and Comox Formations (cont.).

Interval (feet)	Description
	6 in. sandstone Contact gradational over 2 in. 12 in. conglomerate
	Contact sharp, irregular with up to 3 inches relief over 2 feet of contact.
94-93	Silt-clast conglomerate: light gray (N7) to brownish gray (5YR 4/1), weathered; angular siltstone clasts to 12 inches long and sparse rounded fine to medium chert pebbles; grain-supported; matrix is sandstone, medium-grained, rusty-weathering, predominantly quartz and chert. Attitude is N. 75° W., 58° N.
	Contact sharp, undulating; wavelength 3 feet, amplitude 2 to 5 inches.
93-77.5	Conglomerate: cliff-former; olive gray (5Y 4/1), overall weathered aspect; structureless; very fine pebbles to cobbles, predominantly medium pebbles; grain-supported; subangular to rounded; chert and subordinant quartz; matrix is medium- to coarse-grained, poorly sorted sandstone.
	Contact gradational over 4 inches by upward increase in proportion of pebbles.
77.5-70	Pebbly sandstone: cliff-former; incipient honeycomb weathering in spray zone; olive gray (5Y 4/1), weathered; thick-bedded (2 to 3.5 feet); subangular to subrounded; quartz, chert, lithic grains; calcareous; locally this unit contains bands of fine to medium pebbles, subangular to rounded, of chert, quartz, and basalt which define planar foresets 1.5 to 3 inches thick. Attitude is N. 74° W., 60° N.
	At 70 offset 30 feet N. 74° W.
	Contact gradational over 3 feet by upward decrease in proportion of pebbles.
70-0	Conglomerate with sandstone channels: resistant cliff-former. Conglomerate: moderate brown (5YR 4/4), overall weathered aspect; very thick-bedded; fine pebbles to small cobbles, with coarse pebbles predominant; subangular to rounded; grain-supported; chert and minor quartz; matrix is sandstone, medium- to very coarse-grained, angular to rounded, quartz, feldspar, black grains. Sandstone: medium light gray (N6), weathered; light gray (N7), fresh; lenticular, with convex lower surfaces, probably are channels although third dimension is not exposed; range from 1 to 10 feet wide and 4 to 18 inches maximum thickness; structureless; medium- to very coarse-grained; moderately sorted; angular to subrounded; quartz, feldspar, black grains; calcareous;

Measured Section A-B, Cedar District, Extension-Protection, Haslam, and Comox Formations (cont.).

Interval (feet)	Description
	present are scattered matrix-supported fine pebbles of dark chert and quartz.

Contact: Extension-Protection Formation and Haslam Formation; sharp and erosional with 6 inches relief; pebbly sandstone channels 1 to 2 feet wide and 2 to 6 inches deep cut the underlying silty mudstone, channels contain rare mudstone clasts and calcareous mudstone chips identical to Haslam Formation lithologies; 3 channel axes trend N. 70° W., N. 72° W., and N. 85° W.

Haslam Formation (approximate thickness = 673 feet).

Interval (feet)	Description
673-420	Silty mudstone: nonresistant; intertidal shore platform is exposed at low tide; medium dark gray (N4), fresh and weathered; weathers out as platy chips; noncalcareous. Present are calcareous lenses and concretionary zones: light gray (N7), weathered; stand out as resistant ribs and pillows with long axes parallel to bedding; 1 to 12 inches thick, 2 to 20 feet long; spaced at intervals of 2 to 10 feet stratigraphically. 673-643 contains lenticular siltstone laminae: light olive gray (5Y 5/2), weathered; slightly more resistant than surrounding mudstone; 1 to 0.2 inches thick; most are indistinctly cross-laminated. Attitude is N. 55° W., 53° N.
420-360	Covered by intertidal mud at mouth of Cusheon Creek. Attitude used for traverse is N. 60° W., 51° N.
360-70	Concretionary mudstone: interval is partially covered and badly sheared, calcite veins to 0.5 inches wide are present; thickness is at best approximate; dark gray (N3) to medium dark gray (N4), fresh and weathered; tendency to weather into plates about 0.25 inches thick; lenticular concretions, light gray(N7), calcareous, 4 to 5 feet long and up to 1 foot thick are common; also present are spherical to prolate concretions, medium dark gray (N4), calcareous, mostly 2 to 4 inches dimension, one contains an ammonite fossil partially replaced by iron sulfide. Possible fault in base of interval. Contact covered.
70-40	Muddy siltstone: nonresistant; medium dark gray (N4), fresh and weathered; platy tendency; noncalcareous. At 50 offset 400 feet northwest along strike. At 45 are arcuate organic burrows about 0.5 inches diameter on bedding plane resemble _Thalassinoides_.
40-20	Covered by flat siltstone blocks.
20-10	Muddy siltstone as at 70-40. Attitude is N. 64° W., 41° N. Contact covered.

Measured Section A-B, Cedar District, Extension_protection, Haslam, and Comox Formations (cont.).

Interval (feet)	Description
10-0	Silty sandstone to sandy siltstone: medium dark gray (N4), fresh and weathered; platy parting; noncalcareous; contains many spherical concretions, 1 to 2 inches diameter, calcareous, one contains crustacean pincers.

Contact: Haslam Formation and Comox Formation; gradational over 1 foot.

Comox Formation (exposed thickness = 10 feet).

Interval (feet)	Description
10-0	Pebbly sandstone and sandstone: resistant; yellowish gray (5Y 7/2) to olive gray (5Y 3/2), weathered; yellowish gray (5Y 7/2), fresh; platy tendency near top of interval; structureless; fine- to very coarse-grained; poorly sorted; angular; quartz, rock fragments, feldspar; abundant matrix; noncalcareous; contains some fine to very fine pebbles, angular, matrix-supported, quartz, chert, schist; upper part of interval contains a few concretions, calcareous, spherical, 1 foot diameter. At 10 offset 100 feet northwest across fault.

Contact: Comox Formation and Sicker Group; faulted, within Comox Formation, near-vertical fault trends N. 75° E.

Initial point: in Section 75 about 0.5 miles southeast of the mouth of Cusheon Creek at the back of the shore platform where a fault zone 1 foot wide separates sedimentary and metamorphic rocks. Bearings to Nose Point and the terminal point are N. 05° W., and N. 33° W., respectively. At 4 attitude is N. 62° W., 21° N., proceed N. 28° E., up section.

Measured Section C-D, Comox Formation.

Section C-D was measured on the southwest wall of the northwest-trending strike valley of Maxwell Creek at a point about 1.5 miles from the mouth (locally known as Cranberry Outlet) of Maxwell Creek. Here the cuesta-forming Comox Formation exists as a thin cover overlying Sicker Group metamorphics. Within one mile on strike to the northwest, the Comox Formation wedges out and Haslam Formation mudstone directly overlies metamorphic basement.

Terminal point D: about 2000 feet northwest of initial point, is in the south end of lot 14 on the brushy cuesta dip slope under the power line right-of-way between the tower on the cuesta summit in lot 33 and the adjacent tower to the northeast, Saltspring Island.

Contact at D: Haslam Formation over Comox Formation, covered by vegetation (fir, salal, grass, moss), is picked at the top of the highest sandstone outcrop. Mudstone float occurs within 10 feet stratigraphically above highest sandstone outcrop.

Interval (feet)	Description
	Comox Formation with Benson basal conglomerate member (thickness = 297 feet).
297-217	Sandstone and conglomerate. Sandstone: light olive gray (5Y 6/1), weathered; thinly cross-bedded (trough sets) to structureless; very coarse- to fine-grained; moderately to poorly sorted; subangular; quartz, feldspar, magnetite, biotite, epidote; noncalcareous. Conglomerate: light gray (N7), weathered; lenticular channels to 2 feet deep and a few tens of feet wide; subrounded to rounded pebbles to cobbles; schist, phyllite, slightly altered silicic plutonics, metavolcanics, quartz, pyritic quartzite. About 60 percent of this interval is covered by vegetation on the glaciated dip slope.
	Contact gradational over 6 inches and gently undulating.
217-214.5	Conglomerate: light gray (N7), weathered; clasts are grain-supported; subrounded to well rounded; well sorted; pebbles to cobbles (to 8 inches long); schist, phyllite, slightly altered silicic plutonics, metavolcanics, vein quartz, epidote-rich quartz, quartzite; matrix is medium- to coarse-grained sandstone, mineralogy as in subjacent unit.
	Contact gradational over 7 inches from sandstone through pebbly sandstone to conglomerate (not considered to be inverse grading because of distinct bimodality of grain sizes, continuous distribution is precluded by scarcity of very fine- to medium pebbles).
214.5-185	Sandstone: cliff- and cuesta-former; light gray (N7), weathered; yellowish gray (5Y 7/2), fresh; thinly cross-bedded; predominant medium- to fine-grained; moderately to well sorted; angular to subangular; quartz, feldspar, muscovite, biotite, epidote, schist fragments; noncalcareous cement. Stratification is defined by festoon trough cross-bedding; sets are 2 to 6 inches thick and exhibit a predominant northwest component of transport.

Measured Section C-D, Comox Formation (cont.).

Interval (feet)	Description
	This interval includes several thin pebble to cobble conglomerate lenses spaced at intervals of 2 to 6 feet; up to 6 inches thick, and a few tens of feet wide, they consist of subrounded to well rounded clasts to 6 inches diameter of metavolcanics, quartz, schist, slightly altered silicic plutonics, epidote-rich vein quartz.
	Attitude is N. 70° W., 21° N.
185-151	Covered by talus at base of cuesta antidip slope.
151-46	Covered topographic low and swamp; vegetation is salal, tussock, fir. Single outcrop and float is carbonaceous siltstone: medium dark gray (N4); flaggy tendency from concentration of leaf, wood (to 18 inches long), coal flakes and mica on bedding planes; contains 20 to 35 percent very fine pebbles and coarse sand in matrix support; clasts are quartz and schist.
	Contact covered.
46-0	Benson basal conglomerate: cuesta-former; light gray (N7) to medium dark gray (N4), overall aspect; indistinctly thick-bedded; well indurated; dominantly cobbles to boulders (4 to 14 inches diameter); grain-supported; angular to subangular; schist, metavolcanics, vein quartz; matrix is poorly sorted pebbles of similar lithologies.

Basal conglomerate unconformably overlies greenish black (5GY 2/1), slightly foliated Sicker Group metavolcanics. The actual contact is concealed and lies in a low, swampy, grass-covered interval 20 feet wide between the Sicker Group and first conglomerate exposure.

Initial point: on power line right-of-way 0.5 miles north of Lake Maxwell and 200 feet southeast of gravel road in S. 1/2 of E. 1/2 of E. 1/2 of Lot 33, at the base of the southwest side of the low conglomerate ridge, Saltspring Island.

Measured Section D'-E, Extension-Protection Formation, and Haslam Formation.

Section D'-E was measured across the valley and northeast valley wall of Maxwell Creek at a point about 1.25 miles from its mouth (Cranberry Outlet). Nonresistant Haslam Formation underlies the strike valley; the steep northeast valley wall is an antidip slope of the Extension-Protection cuesta. The southwest valley wall is a Comox Formation dip slope (See Measured Section C-D).

The Extension-Protection Formation is grossly divisible into upper and lower conglomerate members which are separated by a more thinly bedded sandstone, conglomerate and mudstone sequence which will be referred to as the middle member.

Terminal point E: within the Extension-Protection Formation upper conglomerate, in the west end of lot 26 on the (newer or northwest) power line right-of-way, at a point about 1400 feet northeast of the tower at the cuesta summit in west end of lot 40, Saltspring Island.

Contact at E: within the upper conglomerate member, at the approximate position of a major fault which trends N. 40° W., north side up, and repeats the upper conglomerate as a cuesta to the northeast.

Interval (feet)	Description

Extension-Protection Formation (minimum thickness = 968 feet).

Upper conglomerate member (thickness = 440 feet). Unit description: conglomerate with minor lenticular sandstones.

Conglomerate: cliff-former; pale yellowish brown (10YR 6/2), overall aspect; very thick-bedded (5 to 60 feet); clasts range from fine pebbles to boulders 6 feet across, coarse pebbles to cobbles predominate; grain-supported; subangular to well-rounded, mostly well-rounded; chert, intermediate to basic volcanics, granite to granodiorite, quartzite, vein quartz, foliated metamorphics, arkose, siltstone. All boulders are white subsilicic plutonics (rarely arkose) and are subangular. Conglomerate matrix: sandstone; very fine- to medium-grained; moderately to poorly sorted; angular to subangular; rusty-weathering; quartz, feldspar, biotite, black grains.

968-528	Conglomerate as in unit description. Lateral to traverse, this interval contains a few sandstone lenses to about 4 feet thick and 60 feet long. Pebble count 85 at 528; pebble count 86 at 778. At 728 probable large-scale cut-and-fill exists. Approximately 10 feet of relief was developed upon structureless conglomerate and then filled by bedded conglomerate (beds 3 to 6 feet thick). The uppermost unit of the infill at its southeast margin is a lens of pebbly sandstone (2.5 feet thick) which bears flat mudstone clasts to 30 inches long.

Contact: upper conglomerate member over middle member; sharp and undulating. Conglomerate appears to rest upon sand waves; wavelength 18 inches, amplitude 2 inches, no discernible asymmetry.

Middle member (thickness = 287 feet).

528-526	Sandstone: exposed under conglomerate overhang; light olive gray (5Y 6/1), fresh; structureless; very fine- to fine-grained; well sorted; angular to subangular; quartz, feldspar, muscovite, biotite, black grains; noncalcareous. Contact covered by slope wash.

Measured Section D'-E, Extension-Protection and Haslam Formations (cont.).

Interval (feet)	Description
526-348	Mostly covered, with isolated exposures of sandstone: ledge-formers; brownish gray (5YR 4/1) to olive gray (5Y 4/1), weathered; thin- to very thin-bedded; flaggy splitting property; with numerous pebble channels and bands to 16 inches thick and 8 feet wide.
	At 428 pebbly sandstone and conglomerate channels bear pelecypod values 0.5 to 1.5 inches across (Glycimerus). They occur in abundance, are disarticulated, unbroken and current oriented (convex upward). Some fragmentary leaf fossils are also present.
	Contact covered.
348-334	Sandstone: cliff-former; medium gray (N5), weathered; thin-bedded (3 to 24 inches); slabby parting; overall normally graded from medium- to very fine-grained; moderately to well sorted; angular to subangular; quartz, feldspar, biotite, black grains; noncalcareous.
	Contact covered.
334-320	Sandstone: cliff-former, medium gray (N5) to pale yellowish brown (10YR 6/2), weathered; laminated (2 per inch); flaggy to thinly platy parting; very fine-grained; well sorted; angular to subangular; quartz, feldspar, muscovite, black grains; noncalcareous; abundant leaf fragments.
320-316	Covered.
316-310	Sandstone: cliff-former, medium gray (N5), weathered; medium light gray (N6), fresh; very thin-bedded to laminated (3 per inch); flaggy to thinly platy parting; fine- to very coarse-grained; moderately to poorly sorted; subangular to subrounded; quartz, rock fragments, muscovite; noncalcareous.
	In the lower half of this interval, stratification is defined by repetitively interbedded to interlaminated fine-grained and medium- to coarse-grained sandstone; contacts are sharp and planar. Cutting the sandstone are conglomerate channels: lenticular; maximum of a few tens of feet wide and 18 inches deep; fine to coarse pebbles; subrounded; predominantly gray chert and green (epidote-rich) quartz; one pelecypod valve present. The upper half of this interval is composed of laminated fine-grained sandstone with well-preserved deciduous leaves, twigs and seeds.
	Contact sharp, gently undulating.
310-304.5	Mostly covered, but two sandstones crop out. Float in covered intervals is mudstone and silty mudstone. Sandstones: ledge-formers; medium light gray (N6) to brownish gray (5YR 4/1), weathered; thin-bedded (6 and 10

Measured Section D'-E, Extension-Protection and Haslam Formations (cont.).

Interval (feet)	Description
	inches thick); normally graded from pebbly coarse-grained to fine-grained sandstone. Contact covered.
304.5-290	Sandstone and conglomerate sequence: cliff-former; pale yellow brown (10YR 6/2), overall aspect. Sandstone: structureless; medium- to coarse-grained; poorly sorted; angular to subangular; quartz, chert, feldspar; noncalcareous. Conglomerate: grain-supported; very fine to medium pebbles; subrounded; gray chert, vein quartz, epidote-rich clasts. Sequence: 54 in. pebbly sandstone Contact gradational over 2 in. 3 in. conglomerate Contact sharp, gently undulating 9 in. sandstone Contact sharp, gently undulating 8 in. conglomerate Contact sharp, gently undulating 24 in. sandstone Contact sharp, gently undulating 4 in. conglomerate Contact sharp, planar 72 in. sandstone Contact sharp, load, flute and groove casts.
290-284	Mudstone and sandstone sequence. Mudstone: dark gray (N4), fresh and weathered; contains some sandy laminae, otherwise is structureless and weathers into chips 0.25 by 0.25 inches. Sandstone: dark yellowish brown (10YR 4/2), weathered; laminated (5 per inch), some indistinct cross-lamination present; very fine- to fine-grained; well sorted; angular to subangular; quartz, feldspar, black grains; noncalcareous. Sequence: 22 in. mudstone Contact sharp, planar 2 in. sandstone Contact sharp, planar 2 in. mudstone Contact sharp, planar 11 in. sandstone Contact sharp, planar 36 in. mudstone Contact covered by talus on sandstone ledge.

Measured Section DLE, Extension-Protection and Haslam Formations (cont.).

Interval (feet)	Description
284-279	Sandstone: light gray (N7), weathered; structureless; medium-grained; moderately sorted; subangular; quartz, feldspar, chert, biotite, magnetite; noncalcareous; contains a few matrix-supported fine to coarse pebbles.
	Contact sharp, planar.
279-270	Conglomerate: dusky brown (5 YR 2/2), overall aspect; structureless except for overall normal grading from medium to fine pebbles; grain-supported; chert, white plutonics, quartz; contains abundant carbonized wood fragments to 25 by 5 inches. This unit is a channel fill and increases in thickness from 9 to 15 feet at a point 50 feet west of traverse where it truncates subjacent sandstone and mudstone.
	Contact sharp, erosional, 6 feet of relief over 50 feet of contact.
270-264.5	Pebbly sandstone: pinkish gray (5YR 2/2) to pale red (5Y 6/2), weathered; very thin-bedded (8 per foot); contains matrix-supported bands (1 pebble thick) of subrounded fine to medium pebbles; chert, white plutonics, quartz; matrix is very fine- to very coarse-grained; poorly sorted; angular to subangular; quartz, feldspar, chert, black and green grains; noncalcareous.
	Contact sharp, erosional, 3 inches relief over 4 feet of contact.
264.5-264	Mudstone: pale brown (5YR 5/2), fresh and weathered; laminated (6 per inch). Because of subsequent erosion and the irregular surface upon which this unit was deposited, it is of variable thickness with a maximum of 6 inches.
	Contact sharp, irregular, 2 inches relief upon channel topography.
264-241	Sandstone and conglomerate. Sandstone: subdued cliff-former; light gray (N7), weathered; very thin- to thin-bedded; flaggy to slabby parting; very fine- to coarse-grained, mostly fine-grained; poorly to moderately sorted; angular to subangular; quartz, feldspar, muscovite, black and green grains; noncalcareous. Near top of the unit are a few fine to very fine pebble lenses which are a maximum of 3 inches thick, a few feet wide, and a contain flat mudstone and siltstone clasts up to 12 inches long. The top of this unit contains a lenticular conglomerate channel which is 20 feet wide, a maximum of 16 inches deep, which truncates underlying sandstone and pebble lenses.

Contact: middle member over lower conglomerate member; sharp and planar.

Lower conglomerate member (thickness = 241 feet).

241-222	Conglomerate: subdued cliff-former; dusky brown (5YR 2/2),

Measured Section D'-E, Extension-Protection and Haslam Formations (cont.).

Interval (feet)	Description
	overall aspect; structureless; very fine pebbles to rare cobbles, predominantly medium pebbles; grain-supported; subangular to rounded; predominantly gray chert, well indurated (silicified?) mudstone, quartzite, with minor feldspathic sandstone, siltstone, volcanics, and metamorphics. Pebble count 78.
	Contact covered.
222-62	Talus- and brush-covered slope; conglomerate and sandstone float.
62-60	Conglomerate: isolated outcrop is draped with talus; dark yellowish brown (10YR 4/2); very fine to coarse pebbles; matrix-supported; clasts are predominantly chert; matrix is fine- to very coarse-grained, poorly sorted sandstone.
	Contact covered.
60-0	Steep talus slope is covered by sandstone and conglomerate blocks from cliff-formers above.

Contact: Extension-Protection Formation and Haslam Formation; covered. Picked at the highest occurrence of mudstone float, which coincides with the base of an abrupt increase in slope.

Haslam Formation (thickness = 600 feet).

Interval (feet)	Description
600-445	Covered by Extension-Protection Formation colluvium and sparse vegetation; rare mudstone float.
445-70	Mostly covered by grass, salal and thistle, but ground is littered with mudstone chips 0.5 by 0.5 inches.
70-25	Silty mudstone: exposed in gulley on east side of old dirt road; nonresistant; medium light gray (N6) to dark yellowish orange (10YR 6/6), weathered; weathers into chips 0.5 by 0.5 inches; platy tendency in outcrop; also exhibits spheroidal weathering such that 7 inch diameter spherical bodies shed concentric layers. Present are abundant carbonaceous flakes, calcareous mudstone concretions, and clay-filled burrows about 1 millimeter diameter. Rare fossils include Inoceramus and uncoiled ammonites.
	Contact poorly exposed, probably gradational.
25-0	Sandy mudstone: nonresistant; light gray (N7) to pale brown (5YR 5/2), weathered; weathers into chips about 1.5 by 1 inches; considerable silt to very coarse sand admixture; recognizable quartz, muscovite; conspicuous mottled texture as a result of burrowing by organisms.

Contact: Haslam Formation and Comox Formation; probably gradational over less than 3 feet; is picked at the upper surface of sandstone dip slope which lies at the base of a 3-foot covered interval below the first sandy mudstone outcrop.

Measured Section D'-E, Extension-Protection and Haslam Formations (cont.).

Interval (feet)	Description

Initial point: at an elevation of 800 feet at a point 1.25 miles southeast of Cranberry Outlet, in west end of lot 32, west side of dirt road under power line right-of-way. D' is about 1000 feet on strike northwest of D, Measured Section C-D.

Measured Section F-G, Lower De Courcy Formation and Middle Cedar District Formation.

Section F-G encompasses strata exposed on the shore platform and in low seacliffs which form the northwest-trending north shore of Booth Bay. An incomplete section of the middle Cedar District Formation is exposed on the shore platform between the fault zone through Booth Inlet and a point about one mile northwest of Booth Inlet. Overlying sandstone of the lower De Courcy Formation underlies the resistant linear ridge which, parallelling the northeast shore of Booth Bay, forms the southwest shore of Vesuvius Bay.

Terminal point G: at top of steep slope on the northeast edge of the sandstone ridge at a point 0.5 miles S. 40° E. of Vesuvius Bay and 200 feet N. 30° W. of an abandoned stone quarry. About 2600 feet separate the terminal and initial points. Bearing to Erskine Point is S. 14° W.

Contact at G: Cedar District Formation, upper member, over lower De Courcy Formation is covered by vegetation; approximate contact is picked at the steep northeast side of the sandstone ridge. At Vesuvius Bay this contact is gradational over a few feet: See contact at H., Measured Section H-I.

Interval (feet)	Description
	Lower De Courcy Formation (Kd_1) (thickness = 292.5 feet).
292.5-13.5	Ridge top littered with large sandstone blocks. Limited outcrops are of sandstone and minor pebbly sandstone: very thick-bedded, to 20 feet thick; coarse- to fine-grained; locally contain matrix-supported very fine pebbles of angular to subangular gray chert and quartz.

Laterally 150 feet northwest of the traverse in an abandoned stone quarry the lower 150 feet of this interval consists of sandstone with minor mudstone and siltstone partings. Sandstone: light gray (N7), weathered; yellow gray (5Y 8/1), fresh; very thick-bedded, predominantly 5 to 20 feet thick; blocky to flaggy parting with mica and carbonized plant debris on bedding planes; fine- to coarse-grained, medium grains predominant; moderately sorted; angular to subangular; quartz, feldspar, biotite (to 0.125 inches), muscovite, black grains; noncalcareous. Within the quarry, sandstone beds appear structureless, but etched surfaces on float and quarried blocks in the tidal zone show inter-laminated coarse and fine sand-size populations, very thin trough cross-beds (sets 1 to 3 inches thick), small-scale scour-and-fill, and flame structure. Sandstone lower contacts are sharp; bases possess numerous sole marks: groove casts (10's of feet long), load casts, flute casts are most abundant; also present are current crescent casts, sand waves with superimposed interference ripples (sand wavelength 6 feet, amplitude 4 to 6 inches, no discernible asymmetry) and primary current lineation (parting lineation). The latter occurs within beds. Where the structures overlap it is apparent that more than one generation of groove casts exists and that groove casts were created prior to load casts.

Mudstone and siltstone: very light gray (N8), weathered and fresh: very thin-bedded, about 0.5 to 6 inches; tendency for platy parting; micaceous; locally varies in thickness along strike; sharp and planar, sharp and gently undulating, and gradational (over 1 to 2 inches) lower contacts are present.

This unit is unfossiliferous except for a few external molds of disarticulated unbroken pelecypod valves (to 5 inches long) and abundant sand-filled organic burrows (0.5 inches diameter). The latter are preserved on sandstone bases. Lith sample WBH-116A at 200 feet.

Contact sharp, load casts; 4 inches relief.

Measured Section F-G, De Courcy and Cedar District Formations (cont.).

Interval (feet)	Description
13.5-0	Well-exposed sandstone and mudstone sequence.

Sandstones: ledge- and cliff-formers; light gray (N7), weathered; yellow gray (5Y 8/1), fresh; thin- to thick-bedded; thinly platy to flaggy parting; individual beds are thinly laminated or laminated; very fine- to very coarse-grained; moderately to poorly sorted; angular; quartz, feldspar, biotite, muscovite, black grains; noncalcareous; some beds possess abundant carbonized leaves, twigs and reeds to 4 inches long, coal flakes to 1 inch long, organic burrows, and rare pelecypod valves (probably Inoceramus) to 2 inches across.

Mudstone: light gray (N7), fresh and weathered; platy parting is imperfectly developed; very thin beds to laminae; slightly micaceous and silty. Lith samples in this interval: WBH-116C and WBH-114.

Sequence:

1. Fine- to medium-grained sandstone, 23 inches; organic burrows. Contact sharp, load casts; 4 inches relief.
k. Mudstone, 4 inches. Contact sharp, gently undulating.
j. Very coarse- to fine-grained sandstone, 30 inches; reverse graded bed. Contact sharp, very planar.
i. Mudstone, 2 inches. Contact sharp, gently undulating.
h. Fine- to very coarse-grained sandstone, 18 inches; normally graded bed. Contact sharp, very planar.
g. Mudstone, 2 inches. Contact sharp, load and flute casts; 1 inch relief.
f. Medium-grained sandstone, 24 inches. Contact sharp, very planar.
e. Mudstone, 0.5 inches. Contact sharp, planar.
d. Medium-grained sandstone, 31 inches; bears fragmented pelecypod valves. Contact sharp, load casts.
c. Fine-grained sandstone, 12 inches; flaggy parting. Contact sharp, load casts; 0.5 inches relief.
b. Very fine-grained sandstone to silty mudstone, 3 inches; normally graded bed, contains thin planar laminations and undulating (rippled) laminations. Contact sharp, gently undulating.
a. Very fine- to fine-grained sandstone, 12 inches; normally graded bed contains planar (3 per inch) and undulating laminations.

Attitude is N. 65° W., 83° N.

Contact: De Courcy Formation, lower member (Kd_1) and Cedar District Formation, middle member; sharp, load casts, 0.5 inches relief.

Cedar District Formation, middle member, base not exposed (approximate minimum thickness = 516 feet).

Measured Section F-G, De Courcy and Cedar District Formations (cont.).

Interval (feet)	Description
516-453	Steep slope covered with mudstone float; dark gray (N3); chips are 0.25 by 0.25 inches; some are silty and sandy. Limited exposures are mudstone: medium dark gray (N4) to dark gray (N3), weathered and fresh; platy, initially weathers into chips about 2 by 2 inches. At 508 is ball-and-pillow structure; isolated ellipsoids of very fine- to medium-grained sandstone about 1 foot in diameter lie in mudstone matrix. The sandstone bodies are internally thinly laminated with contorted lamination. Contact covered by mudstone and sandstone talus.
453-418	Shore platform is covered by sandstone blocks. Laterally 300 feet northwest this interval is exposed and consists of rhythmically thinly interbedded mudstone and siltstone as at 418-173. At 418 offset 600 feet northwest along strike.
418-173	Rhythmically interbedded mudstone and siltstone sequence forms weakly ribbed foreshore. Mudstone: medium gray (N5) to dark gray (N3), fresh and weathered; noncalcareous; tendency to weather into chips 0.5 by 0.5 inches; contains light gray (N7) lenticular concretions 1 to 4 inches thick and 6 to 24 inches long which usually contain large unbroken and often articulated pelecypod valves up to 6 inches long. Probably <u>Inoceramus</u>. Siltstone: thin rib-formers; light olive gray (5GY 6/1), weathered; light gray (N7), fresh; very thin-beds to laminations (2 to 0.25 inches thick); internally thinly laminated and cross-laminated; sharp and planar bases and tops except for burrows and rare load casts and flute casts on bases. At 388 offset 600 feet northwest along strike to maintain stratigraphic position on high-tide shore platform. At 248 offset 750 feet northwest along top of bed. At 218 offset 550 feet northwest along strike. Contact covered.
173-73	Covered by mudflat and oyster beds.
73-0	Strongly ribbed intertidal area is poorly exposed due to marine life; rhythmically interbedded sandstone, siltstone and mudstone. Resistant sandstone ribs are maximum of 2 feet thick.

Contact: within the middle Cedar District Formation is water level at a tide of plus 3 feet at the mouth of Booth Inlet, but ribbed sequence is visible under water, 15 feet offshore.

Initial point: waterline at a low tide of plus 3 feet on the northeast shore of Booth Bay at a point about 600 feet northwest of the mouth of Booth Inlet. Bearings to Erskine Point and the narrows at the mouth of Booth Inlet are S. 29° W. and S. 50° E., respectively. Attitude is N. 73° W., 79° N., proceed N. 17° E., up section.

Measured Section H-I, Cedar District Formation.

Section H-I, encompassing the upper Cedar District Formation, was measured across Vesuvius Bay from the top of De Courcy Formation, Tongue 1 (Kd_1) to the base of De Courcy Formation, Tongue 3 (Kd_3). The section consists of steeply northeast-dipping strata of the west limb of the Kulleet Syncline. Excellent exposures of unweathered bedrock exist on the shore platform at low tide; only 35 percent of the section is covered. Section H-I was measured to provide a detailed account of thicknesses, lithologies, and sedimentary structures of the Cedar District Formation, upper member.

Terminal point I: coincides with initial point I' of Measured Section I'-J; about 50 feet above high-tide mark on the northeast side of Vesuvius Bay and southwest side of Dock Point, about 1150 feet northwest of Vesuvius Ferry landing; bearings to the ferry landing and the sharp point on west side of Vesuvius Bay are S. 24° E. and S. 02° E., respectively.

Contact at I: De Courcy Formation, Tongue 3 (Kd_3) and Cedar District Formation, main member; sharp and planar. (See contact at I', Measured Section I'-J.)

Interval (feet)	Description

Unit 4-unit description (thickness = 421 feet): Repetitively interbedded sandstone, siltstone and mudstone sequence: similar to unit 3, but sandstone beds are noticeably thinner; sandstone and siltstone comprise up to 80 percent of the lower part of unit 4.

Sandstone and siltstone: resistant rib-formers; light olive gray (5Y 5/2) to medium gray (N5), weathered; medium light gray (N6), fresh; very thin to very thick beds (maximum of 5 feet, but usually do not exceed 1 foot); rarely lenticular, most are parallel-sided and laterally continuous in outcrop; most are normally graded, parallel laminated, and possess undulating or contorted lamination; also present are cross-lamination, ripple-drift cross-lamination and contorted cross-lamination. Bases are sharp and mostly planar, with frequent load and flame structures; most tops of sandstone beds grade into overlying finer grained intervals. Sandstones are coarse- to very fine-grained, moderately sorted, angular to subangular, quartz, feldspar, biotite, muscovite, rock fragments, slightly calcareous, with limited carbonaceous matter on bedding planes.

Mudstone: nonresistant interbeds; medium gray (N5), fresh and weathered; tendency for platy parting; commonly mottled by organic burrows.

1447-1393	Thickness approximate because of difficulty in measuring on steep backshore slope; talus and brush cover; interrupted outcrops of thinly interbedded mudstone and sandstone. Contact concealed by talus.
1393-1173	Sequence of predominantly normally graded sandstone to siltstone beds which are rhythmically repetitively interbedded with mudstone. Stratification overall notably thinner than in the lower part of unit 4. Sandstone: predominantly very thin to thin beds (1 to 3 inches thick), rare beds to 5 feet thick are present; internally thinly laminated (about 14 per inch), with abundant cross-laminations (often with asymmetrical ripple profiles) and contorted laminations. Foresets of cross-laminations are invariably inclined along strike to the northwest as seen in two dimensions.

Measured Section H-I, Cedar District Formation (cont.).

Interval (feet)	Description
	A representative 10 foot sequence is detailed below:
	y. Medium-grained sandstone to argillaceous siltstone, 4.00 feet; normal grading is of two types: coarse-tail grading is defined by occurrence of very coarse-sand grains near base of bed and their upward decline and disappearance at center of bed; delayed normal grading results in bed which is medium-grained except for upper few inches; structureless lower half contains ripped-up strata to 6 feet long, some of which are still connected to subjacent beds, rip-ups are deformed into rolls and folds which suggest transport to the northwest; top of bed is laminated (5 per inch), undulating (sinusoidal ripple lamination) lamination, platy parting, burrowed. Contact sharp, varies from loaded to erosional (ripped-up subjacent beds).
	x. Fine-grained sandstone to silty mudstone, 0.40 feet; normally graded; thinly laminated lower half is platy, some contorted lamination; varies in thickness along strike from 0.32 to 0.58 feet as result of truncation by and incorporation into overlying bed. Contact sharp, load casts; 0.25 inches relief.
	w. Fine-grained sandstone to silty mudstone, 0.19 feet; normally graded; indistinctly thinly laminated; finely burrow mottled. Contact sharp, gently undulating.
	v. Normally graded bed similar to w., 0.15 feet. Contact sharp, planar.
	u. Mudstone, 0.25 feet; sand-filled burrows are 0.5 inches maximum diameter and elliptical in cross-section. Contact sharp, 0.5 inches relief upon contorted top of bed t.
	t. Very fine-grained sandstone, 0.15 feet; undulating (sinusoidal ripple) lamination and contorted laminations throughout. Contact sharp, gently undulating.
	s. Very fine-grained sandstone to argillaceous siltstone, 0.17 feet; normally graded, lower part contains some cross-lamination (current to northwest). Contact sharp, varies from gently undulating to loaded.
	r. Normally graded bed as at s., 0.06 feet. Contact sharp, planar.
	q. Very fine-grained sandstone to silty mudstone, 0.25 feet; normally graded, thinly laminated. Contact sharp, gently undulating.
	p. Normally graded bed as at q., 0.33 feet. Contact sharp, gently undulating.
	o. Normally graded bed as at q., 0.27 feet. Contact sharp, gently undulating.

Measured Section H-I, Cedar District Formation (cont.).

Interval (feet)	Description
	n. Very fine-grained sandstone to silty mudstone, 0.25 feet; normally graded with contorted laminations in basal 1 inch. Contact sharp, load casts with less than 0.25 inches relief.
	m. Siltstone to mudstone, 0.06 feet; normally graded and thinly laminated. Contact sharp, gently undulating.
	l. Normally graded bed as at m., 0.08 feet. Contact sharp, gently undulating.
	k. Mudstone, 0.12 feet. Contact sharp, gently undulating.
	j. Very fine-grained sandstone to mudstone, 0.33 feet; normally graded; dusky yellow (5Y 6/4), weath., olive black (5Y 3/1), fresh; thinly laminated (20 per inch) with undulating and contorted laminations. Contact sharp, gently undulating.
	i. Normally graded bed as at q., 0.23 feet; with minute organic burrows. Contact sharp, load casts with 0.125 inches relief.
	h. Normally graded as at q., 0.33 feet; slightly calcareous and incipient honeycomb weathering. Contact sharp, gently undulating.
	g. Normally graded bed as at q., 0.27 feet; base contains some cross-laminations (current to northwest). Contact sharp, gently undulating.
	f. Normally graded bed as at q., 0.31 feet. Contact sharp, gently undulating.
	e. Very fine-grained sandstone to silty mudstone, 0.25 feet; normally graded, basal part thinly laminated, top half intensely burrow mottled. Contact sharp, gently undulating.
	d. Normally graded bed as at q., 0.59 feet; upper half burrow mottled. Contact sharp, load casts with 0.25 inches relief.
	c. Normally graded bed as at q., 0.25 feet; yellowish gray (5Y 8/1), weath., locally cross-laminated (current to northwest). Contact sharp, gently undulating.
	b. Normally graded bed as at q., 0.38 feet; platy parting and sand-filled burrows. Contact sharp, gently undulating.
	a. Very fine-grained sandstone, 0.96 feet; greenish gray (5GY 6/1), fresh and weath.; thinly laminated (18 per inch), and abundant contorted laminations.
	At 1353 offset 250 feet to northwest along top of bed to avoid cliff face.
	1343-1313 is partially covered by sandstone blocks from cliffs above.

Interval (feet)	Description
	At 1313 is a structureless medium-grained sandstone 3 feet thick which has spherical concretions to 2.5 feet diameter which are calcareous and weather out in relief.
	At 1278 offset 100 feet northwest along top of bed. Lith sample WBH-111.
	At 1223 a calcareous mudstone concretion is involved in folds of soft sediment deformation.
	1223-2318 is a medium- to fine-grained sandstone bed which encloses ripped up subjacent beds; the latter are a maximum of 25 feet long and 1 foot thick and exist as recumbent and overturned folds with wavelengths from 4 to 36 inches and amplitudes from 4 to 70 inches.
	At 1173 offset 200 feet northwest along top of sandstone bed.
1173-1129	Rhythmic sequence as in unit description: a representative 10 foot sequence is detailed below: (1140.8-1129)

m. Coarse-grained sandstone to siltstone, 2.1 feet; normally graded; siltstone is thinly laminated. Contact sharp, planar.

l. Mudstone, 0.8 feet; abundant horizontal burrows to 0.75 inches diameter. Contact gradational over 1.5 inches from siltstone to mudstone.

k. Coarse-grained sandstone to siltstone, 2.0 feet; normally graded; siltstone is thinly laminated and upper half of bed contains many mud rip-ups to 3 feet long. Contact sharp, planar.

j. Mudstone, 0.8 feet; abundant sand-filled burrows; top of interval is light gray micritic mudstone. Contact gradational over 1 inch.

i. Fine-grained sandstone to siltstone, 0.7 feet; laminated (10 per inch) throughout with undulating (sinusoidal) laminations in middle of bed. Contact sharp, gently undulating.

h. Mudstone, 0.3 feet; sand-filled horizontal burrows. Contact gradational over 0.5 inches.

g. Medium-grained sandstone to siltstone, 0.6 feet; normally graded; top indistinctly laminated. Contact sharp, gently undulating.

f. Mudstone, 0.3 feet; horizontal sand-filled burrows; lenticular micritic concretions, parallel bedding, light gray (N8), 0.5 inches thick by 24 inches long. Contact gradational over 0.5 inches.

e. Siltstone, 0.3 feet; thinly laminated (24 per inch); burrowed. Contact sharp, load casts with 0.25 inches relief.

d. Mudstone, 0.3 feet; burrowed. Contact gradational over 1 inch.

Measured Section H-I, Cedar District Formation (cont.).

Interval (feet)	Description
	c. Coarse-grained sandstone to siltstone, 1.6 feet; normally graded, upper half thinly laminated with some undulating laminations and cross-laminations. Contact sharp, load casts with 0.5 inches relief. Lith sample WBH-110.
	b. Mudstone, 0.8 feet; abundant horizontal sandstone-filled burrows about 0.5 inches diameter. Contact gradational over 1 inch.
	a. Medium-grained sandstone to argillaceous siltstone, 1.0 feet; normally graded, upper half thinly laminated (about 20 per inch) and contains some undulating laminations (sinusoidal) ripple lamination) (wavelength 1-2 inches, amplitude 1 inch), cross-laminations and over-steepened cross-laminations.
1129-1104	Covered by beach gravel.
1104-1078	Rhythmically repetitively interbedded sequence as in unit description; consists of about 80 percent sandstone-siltstone ribs from 1 to 40 inches thick.
1078-1026	Covered by beach gravel.

Unit 3-unit description (thickness = 353 feet): Thick to very thick sandstone beds alternate with less resistant intervals of thinly interbedded sandstone, siltstone and mudstone.

Sandstones: resistant rib-formers; tendency to honeycomb weathering in spray zone; light olive gray (5Y 6/1), weathered; medium light gray (N6), fresh; thick- to very thick-bedded (maximum of 7 feet); structureless, or normally graded with laminated and platy top; lower contacts always sharp, range from very planar to groove and load casts; upper contacts mostly sharp, planar or gently undulating, but some are gradational; coarse- to very fine-grained; poorly to moderately sorted, finer grained upper parts of graded beds show higher degree of sorting than lower parts of same beds; angular to subangular; quartz, feldspar, muscovite, biotite, chert; noncalcareous; appreciable intergranular matrix often present. Commonly incorporated in, or constituting an appreciable part of resistant sandstone ribs, are large (some exceed 10 feet in length) ripped up sheets of thinly bedded mudstone, siltstone and sandstone which are folded, rolled, and commonly seen to be still connected to subjacent strata.

Less resistant intervals consist of repetitively bedded mudstones and normally graded and/or thinly laminated sandstone to siltstones as in upper part of unit 4.

1026-878	Normally graded sandstones 2 to 7 feet thick are separated by intervals 1 inch to 3 feet thick of mudstone and siltstone.
	1018-1011 is coarse-grained sandstone to siltstone bed; normally graded; top 1 foot is thinly laminated (20 per inch) siltstone; contains ripped up beds of thinly laminated siltstone which are contorted and up to 10 feet long.
	At 970.5 offset 200 feet along top of bed to maintain position on foreshore.
	At 943 offset N. 68° W., 150 feet.

Measured Section H-I, Cedar District Formation (cont.).

Interval (feet)	Description
	At 941 are groove casts which trend N. 20° E.
	Contact sharp, load casts with 1 inch relief.
878-841.5	Mostly covered. A few resistant sandstone ribs about 2 feet thick crop out.
	Offset 50 feet northwest along top of bed.
841.5-837.5	Sandstone rib: honeycomb weathering; structureless except for probable coarse-tail grading as defined by occurrence of angular very fine pebbles of gray chert in basal 6 inches.
	Contact sharp, load casts with 2 inches relief; 6 feet to southeast of traverse this contact is erosional where fine-grained top of bed is truncated.
837.5-834.5	Medium-grained sandstone to silty mudstone: normally graded; top 6 inches is thinly laminated with some contorted laminations and sand-filled burrows.
	Contact sharp, load casts with 1 inch relief.
834.5-831.5	Normally graded bed as at 837.5-834.5.
	Contact sharp, planar.
831.5-831	Covered.
831-829.3	Structureless, fine-grained sandstone rib.
	Contact sharp, planar.
829.3-826.3	Nonresistant covered interval.
826.3-824.3	Structureless sandstone rib: not visibly graded; medium- to fine-grained.
	Contact sharp, load casts with 0.5 inches relief.
824.3-823.3	Interlaminated siltstone and mudstone; interval contains a 1 inch thick sandstone; abundant sand-filled burrows present.
	Contact gradational over 1 inch from underlying siltstone at top of graded bed to mudstone.
823.3-820.8	Normally graded sandstone rib: medium-grained sandstone to siltstone; top 2 inches are thinly laminated, contain some trough cross-laminations and vertical sand-filled burrows 0.25 inches diameter.
	Contact sharp, planar.
820.8-819.5	Normally graded sandstone to siltstone as at 823.3-820.8.
	Contact sharp, planar and erosional.
819.5-818.2	Contorted siltstone and mudstone; locally rolled into balls.

Measured Section H-I, Cedar District Formation (cont.).

Interval (feet)	Description
	Contact sharp, irregular; with up to 1 foot relief on topography of subjacent bed.
818.2-816.2	Structureless medium- to fine-grained sandstone rib. Superjacent interval is probably the deformed top of this originally normally graded bed.
	Contact sharp, planar.
816.2-812.7	Interbedded sequence of thinly laminated siltstones (maximum of 4 inches thick) and mudstones (maximum of 2 inches thick) constitute recumbent folds with wavelengths of about 1 foot and amplitudes of about 2 to 4 feet and no preferential direction of overturning. Abundant burrows with medium-grained sandstone infills cut the folded beds and clearly postdate the deformation.
	Contact sharp, gently undulating.
812.7-812.2	Sandstone rib: tendency to honeycomb weathering; indistinctly laminated (about 6 per inch); medium- to fine-grained; 20 feet to southeast and 15 feet to northwest this bed has increased to 1.5 feet thick; contains a few mud rip-ups to 9 inches long.
	Contact sharp, planar.
812.2-810	Heterogeneous assortment of mudstone and siltstone rip-ups lie in a medium- to fine-grained sandstone matrix.
	Contact covered.
810-805.5	Structureless sandstone rib.
	Contact sharp, gently undulating.
	Offset 50 feet northwest along bedding plane to avoid cliff face.
805.5-802.5	Normally graded sandstone rib: coarse-grained sandstone to siltstone; top 10 inches burrow mottled and indistinctly thinly laminated.
	Contact sharp, load casts with 0.5 inches relief.
802.5-797	Normally graded sandstone rib: medium-grained sandstone to siltstone; bottom 4.5 feet structureless, top 1 foot laminated; top 3 to 4.5 feet contains many laminated siltstone and mudstone rip-ups to 3 feet long.
	Contact sharp, planar.
797-789	Mostly covered; exposures as at 783.5-765.
	Contact sharp, gently undulating.
789-783.5	Medium-grained sandstone rib: structureless, not visibly graded; contains a few mud rip-ups.

Interval (feet)	Description
	Contact sharp, gently undulating.
783.5-765	Mostly covered. Some outcrops of very thin-bedded to laminated mudstone and siltstone, and structureless sandstone ribs to 1 foot thick.
	Contact covered.
	Offset 50 feet northwest along bedding plane.
765-758.7	Sandstone as at 789-783.5. Attitude is N. 68° W., 78° N.
	Contact covered.
758.7-737.2	Mostly covered. Exposures are of thick sandstone beds (2 to 4 feet) which contain a large proportion of contorted intraformational rip-ups.
	Contact covered.
737.2-733.4	Resistant sandstone rib contains a few mudstone rip-ups to 3 feet long.
	Offset 120 feet northwest along bedding plane.
733.4-713.3	Covered. Nonresistant interval.
	Contact covered.
713.3-706.5	Normally graded sandstone rib: medium-grained sandstone to siltstone; contains a heterogeneous assortment of contorted intraformational rip-ups which make up an appreciable if not predominant part of the bed. Many of the clasts are in grain support.
	Contact sharp, planar.
706.5-704	Mostly covered. Exposures are of mudstone with minor very thin interbeds of siltstone as in unit 2.
	Contact covered.
704-696.6	Normally graded sandstone: very coarse-grained to siltstone; top 6 inches thinly laminated; contains a large proportion of contorted mudstone and siltstone rip-ups to 10 feet long and 10 inches thick which are indistinguishable from the subjacent unit.
	Lith sample WBH-109.
	Contact sharp, planar.
696.6-694.4	Mudstone and siltstone as at 706.5-704.
	Contact sharp, gently undulating.
694.4-690.7	Heterogeneous assortment of contorted intraformational rip-ups of siltstone and fine-grained sandstone lie in a matrix of

Measured Section H-I, Cedar District Formation (cont.).

Interval (feet)	Description
	sandstone which is overall normally graded from medium- to fine-grained. The clasts constitute 50 percent of the bed and have maximum dimensions of 6 feet by 10 inches.
	Contact sharp, planar.
690.7-678.2	Mudstone with minor thin beds to laminae of fine-grained sandstone to siltstone, as in unit 1.
	Contact sharp, irregular; 1 foot relief upon top of disturbed underlying bed.
	Offset 50 feet northwest along top of bed.
678.2-675.7	A bed of fine-grained, laminated sandstone which varies from 3 to 12 inches thick exists as recumbent folds enclosed in a matrix of mudstone and medium- to coarse-grained sandstone. Twenty feet to the southeast the fine-grained bed is undisturbed and constitutes the basal part of this interval. The bed which contains the folded unit is in turn truncated by a lenticular coarse-grained sandstone which is 20 feet wide and 16 inches thick at its center.
	Contact sharp, irregular with 6 inches relief.
675.7-674.2	Thinly interbedded mudstone, siltstone and sandstone as in unit 1. Thickness varies along strike (14-30 inches) as a result of local incorporation into overlying bed as soft sediment folds.
	Contact sharp, planar.
674.2-673	Sandstone rib: as in unit description; mostly structureless except for some platy parting and contorted laminations in upper and lower thirds.

Contact: unit 3 and unit 2; sharp, planar; arbitrarily picked where rib-formers persistently exceed 1 foot in thickness above the contact.

Unit 2-unit description (thickness = 538.5 feet): Primarily a sequence of concretionary and fossiliferous mudstones with rhythmically interbedded siltstone laminae.

Mudstone: comprises about 80 percent of the unit; medium dark gray (N4) to medium gray (N5), fresh and weathered; commonly crossed by silt- or sand-filled burrows. Contains abundant calcareous concretions and beds: light gray (N7), weathered; concretions are ellipsoidal in cross-section; maximum of 4 inches thick; some are pyritic and rusty-weathering (10YR 6/6).; commonly contain pelecypod fossils, valves are up to 0.125 inches thick and 1 foot long, prismatic character of carbonate suggests Inoceramus; some concretions are crossed by organic burrows which extend into surrounding noncalcareous mudstone; mudstone matrix often bends around the concretions by arching of the platy parting over and under the calcareous bodies.

Siltstone and sandstone interbeds: light olive gray (5Y 5/2), weathered; medium light gray (N6) to light gray (N7), fresh. The lower 300 feet of unit 2 consists of mudstone with siltstone laminae and lenticular laminae which are a maximum of 0.75 inches thick, thinly laminated, and/or cross-laminated, and vary in thickness along strike. Upward in the unit the interbeds gradually become

Measured Section H-I, Cedar District Formation (cont.).

Interval (feet)	Description

thicker, constitute a greater proportion of the section, are parallel-sided and laterally continuous in outcrop, and contain slightly coarser grains (maximum is very fine-grained sandstone). They invariably possess laminations, and commonly possess contorted and cross-laminations. Weathered upper and lower contacts are sharp and planar to gently undulating.

Lith sample WBH-108 at 442.5.

A representative 41-inch sequence from the lower part of unit 2 follows.

Sequence:
7.8 in. mudstone
0.2 in. siltstone
2.5 in. mudstone
0.5 in. siltstone
12.5 in. mudstone
0.1 in. siltstone
2.5 in. mudstone
0.1 in. siltstone
1.2 in. mudstone
0.8 in. siltstone
3.3 in. mudstone
0.2 in. siltstone
1.1 in. mudstone
0.6 in. siltstone
2.0 in. mudstone with vertical siltstone-filled burrows
0.1 in. siltstone
2.0 in. mudstone
0.5 in. siltstone
3.0 in. mudstone

At 340 attitude is N. 68° W., 72° N.

339.5-134.5	Covered by mudflats and gravel in Vesuvius Bay.

Contact: unit 2 and unit 1; covered; arbitrarily picked at base of nonresistant covered interval.

Unit 1-unit description (thickness 134.5 feet): Rhythmically interbedded siltstone, sandstone and mudstone; forms a ribbed foreshore which is exposed at low tide.

Fine-grained sandstone to siltstone: resistant rib-formers; dusky yellow (5Y 6/4) to medium gray (N5), weathered; medium gray (N5), fresh; thin beds (2 to 9 inches thick) average about 2 inches; where not encrusted with sea life, weathered surfaces show laminations to thin laminations, cross-laminations, platy parting, and locally soft sediment folds. Beds commonly consist of a basal cross-laminated to thinly cross-bedded zone which is overlain by an upper thinly laminated zone. As seen in two dimensions, foresets of cross-laminations are invariably inclined to the northwest. Weathered lower contacts are sharp and planar; weathered upper contacts are sharp and gently undulating. However, they may be gradational over less than 1 inch by normal grading from siltstone to mudstone.

Mudstone: nonresistant; medium gray (N5), weathered; very thin-bedded to thin-bedded (1 to 14 inches); contain scarce lenticular siltstone laminae 1 to 2 feet long which contain cross-laminations.

Measured Section H-I, Cedar District Formation (cont.).

Interval (feet)	Description
134.5-94.5	Fifty percent covered by beach gravel: exposures are very thin-bedded sandstones and thick-bedded mudstones. Resistant sandstone to siltstone ribs are mostly less than 1 to a maximum of 7 inches thick. Attitude is N. 69° W., 72° N.
	Contact covered.
94.5-61.5	Interrupted intertidal exposures as in unit description. Sequence is about 40 percent sandstone and siltstone.
	Contact covered.
61.5-46.5	Rhythmically bedded sequence as in unit description. Sandstones and mudstones are a maximum of 8 and 14 inches thick, respectively.
	Contact sharp, gently undulating upon irregular surface of soft sediment folds.
46.5-46	Sandstone: resistant rib-former; light olive gray (5Y 5/2), weathered; medium dark gray (N4), fresh; overall normally graded from very fine-grained sandstone to silty mudstone; lower half is thinly laminated, upper half consists of contorted laminations and recumbent soft sediment folds, folds are all overturned to the northwest and have wavelengths and amplitudes of less than 5 inches. This bed thins to 3 inches at a point 100 feet to the southeast.
	Contact sharp, planar.
	Offset 150 feet S. 70° E., along strike.
46-0	Rhythmically bedded sequence as in unit description is characterized by an overall upward decrease in thickness of rib-formers and increase in proportion of mudstone. Non-resistant interbeds in the basal few feet of the interval are interlaminated siltstone to very fine-grained sandstone; locally with minute ripples, scour-and-fill, and organic burrows. Mudstone is the dominant lithology in the upper part of this interval. A representative 36-inch sequence from the upper part of this interval follows.
	Sequence: 1.8 in. siltstone 2.0 in. mudstone 0.9 in. siltstone 5.0 in. mudstone 1.1 in. siltstone 2.2 in. mudstone 1.3 in. siltstone 3.7 in. mudstone 0.2 in. siltstone 0.8 in. mudstone

Measured Section H-I, Cedar District Formation (cont.).

Interval (feet)	Description
	0.8 in. siltstone
	2.7 in. mudstone
	1.5 in. siltstone
	2.8 in. mudstone
	0.7 in. siltstone
	2.0 in. mudstone
	0.8 in. siltstone
	1.2 in. mudstone
	1.0 in. siltstone
	3.4 in. mudstone
	0.8 in. siltstone

Contact: Cedar District Formation, upper member of De Courcy Formation, Tongue 1 (Kd_1); sharp and planar where arbitrarily picked at the top of sandstone bed three feet thick. This contact is best described as gradational by an upward decrease in sandstone bed thickness and grain size and concomitant increase in proportion of mudstone. The transition from thick- and very thick-bedded sandstone of Kd_1 to thin-bedded sandstones and siltstones of the Cedar District Formation occurs over about 10 feet stratigraphically. Lith sample WBH-106 of uppermost Kd_1 sandstone.

Initial point: on the upper surface (northeast face) of the thick sandstone rib which forms the southwest shore of Vesuvius Bay, on the high-tide mark at a point about 200 feet southwest from the north end of the rib, one hour after a low tide of plus 1.6 feet. Attitude is N. 68° W., 69° N., proceed N. 22° E., up section.

Measured Section I'-J, Northumberland Formation and upper De Courcy Formation.

Section I'-J, encompassing the upper De Courcy and Northumberland Formations, was measured at Dock Point and Duck Bay on the northwest coast of Saltspring Island. The De Courcy Formation here consists of two tongues which form the resistant twin ribs of Dock Point, the northeast shore of Vesuvius Bay, and the southwest shore of Duck Bay. The intervening reentrant at Dock Point is formed by a less resistant Northumberland Formation tongue. Duck Bay is formed by the main body of the Northumberland Formation and bordered on the northeast by Geoffrey Formation sandstone cliffs. All units lie on the steeply northeast-dipping west limb of the Kulleet Syncline.

Terminal point J: at the base of sandstone blocks in the tidal zone on the northeast shore of Duck Bay, approximately 600 feet northwest of the point where Duck Creek intersects the tidal mudflats.

Contact at J: within the upper Northumberland Formation, is covered by sandstone blocks and mudflats but is probably no more than 100 feet stratigraphically below Geoffrey Formation sandstone.

Interval (feet)	Description
	Northumberland Formation (minimum thickness = 479 feet). Unit description: mudstone with minor siltstone laminae; nonresistant, bay- and valley-former; medium dark gray (N4) to medium gray (N5), fresh and weathered; platy, initially weathers into dimensions by 2 by 2 by 0.3 to 0.5 inches; noncalcareous; bears large calcareous concretions, light gray (N7) weathered, which are lenticular and a maximum of 6 feet long and 10 inches thick; present are 10 percent or less of siltstone laminae and lenticular laminae: light gray (N7), fresh; light olive gray (5Y 6/1), weathered; predominantly less than 0.5 inches thick; commonly disturbed by bioturbation, or thinly laminated and cross-laminated;sharp, planar bottoms, tops grade from siltstone to muddy siltstone to mudstone over about 0.5 inches.
479-270	Covered by mudflats in Duck Bay. Outcrops in this interval 600 feet to the southeast at the head of Duck Bay are silty mudstone as in unit description. Attitude of rocks is N. 66° W., 60° N.
270-10	Mudstone and siltstone as in unit description. The lower 30 feet of this interval contains very thin interbeds (0.5 to 2 inches thick) of very fine-grained sandstone to siltstone which are thinly laminated. Contact sharp and planar; artibrarily placed where rib-formers become predominantly less than 2 inches thick (very thin beds).
10-0	Ribbed intertidal area is poorly exposed because of encrusting barnacles. Repetitively interbedded sandstone or siltstone and mudstone: very fine-grained sandstone and siltstone; resistant rib-formers; medium gray (N5) to light olive gray (5Y 6/1), weathered; thin to very thin beds (2 to 12 inches); internally laminated to thinly laminated; rib thickness decreases upward, only the thickest ribs (at bottom of the interval) are sandstone; non-resistant interbeds are silty mudstone.

Measured Section I'-J, Northumberland and De Courcy Formations (cont.).

Interval (feet)	Description

Contact: Northumberland Formation, main body, and De Courcy Formation, Tongue 4 (Kd_4); sharp and planar.

De Courcy Formation, Tongue 4 (Kd_4) (thickness = 144 feet).

144-0	Thick- to very thick-bedded sandstone (2 to greater than 4 feet thick) as in Kd_2, below. Attitude is N. 60° W., 65° N. At 114 offset 150 feet southeast around point.

Contact: De Courcy Formation, Tongue 4 (Kd_4) and Northumberland Formation, Tongue 1 (Kn_1); covered by mud in small bay.

Northumberland Formation, Tongue 1 (Kn_1) (thickness = 106 feet).

106-50	Nonresistant: covered by mud in small bay.
50-0	Ribbed intertidal area; overall nonresistant; resistant ribs are thin sandstone beds (4 to 12 inches thick); platy parting; internally laminated to thinly laminated, some undulating (sinusoidal ripple) lamination and contorted lamination present; very fine- to fine-grained; moderately sorted; angular; quartz, muscovite, black grains; nonresistant interbeds are 2 to 20 inches thick and covered by mud, gravel and encrusting marine life. Limited exposures are of mudstone and muddy siltstone. At 0 offset 250 feet southeast along bedding plane.

Contact: Northumberland Formation, Tongue 1 (Kn_1) and De Courcy Formation, Tongue 3 (Kd_3); sharp and planar, at upper surface of a sandstone bed 30 feet thick.

De Courcy Formation, Tongue 3 (Kd_3) (thickness = 215 feet). Unit description: sandstone with thin mudstone and siltstone interbeds and partings; forms the resistant rib of Dock Point.

Sandstones: resistant rib-, ledge-, and cliff-formers; yellowish gray (5Y 7/2), weathered; medium gray (N5), fresh; cavernous and honeycomb weathering occurs just above the high-tide line in the spray zone; thin- to very thick-bedded, 3 inches to 33 feet, but mostly 2 to 10 feet thick; blocky to slabby parting caused by concentrations of mica parallel to bedding and preferred orientation of other grains (the latter indicated by parting lineation); beds appear structureless, but etched surfaces in the tidal zone show laminations (3 per inch), undulating laminations (wavelength 1 foot, amplitudes to 3 inches), thin trough crossbeds (sets 3 inches thick, 2 feet wide), asymmetrically back-filled organic burrows; some of the thinner beds are normally graded (as at 132 feet where a 36 inch bed is graded from coarse- to fine-grained sandstone); contain rare mud rip-ups to 1 foot long; commonly contain spherical calcareous concretions to 4 feet diameter which weather out in relief and often possess honeycomb weathering; some concretions exposed well above the spray zone are selectively weathered to friable yellow brown (10YR 3/2) sandstone; upper contacts are sharp and planar, lower contacts are sharp and possess abundant sole marks (groove and flute casts, frondescent marks, organic burrows about 0.5 inches diameter); sandstones are fine- to very coarse-grained; poorly to moderately sorted; angular to subrounded; quartz, feldspar, muscovite, biotite, dark grains; some carbonized leaf and wood fragments to 0.5 inches dimension are present.

Measured Section I'-J, Northumberland and De Courcy Formations (cont.).

Interval (feet)	Description

Silty mudstone: nonresistant interbeds and partings; medium light gray (N6), fresh and weathered; platy, break into chips up to 4 by 4 by 0.5 inches; thinly laminated (20 per inch); commonly micaceous; beds range from a fraction of an inch to 6 inches thick and locally vary in thickness from loading and probable truncation.

215-0	Sandstone with minor mudstone as in unit description; mudstone interbeds give way to thinly laminated siltstones in upper half of the unit where some thick sandstones possess interlamination of coarse and fine sand-size populations. Overall, sandstone bed thickness and grain size increase upward in this unit. At 186: conglomerate lens; 1 foot thick, 10 feet wide; very fine to fine pebbles; angular; chert and milky quartz. Pebbly trough cross-bed axis trends N. 55° W., foresets are inclined to the northwest. At 150 attitude is N. 60° W., 65° N. At 135 offset 600 feet northwest along bedding plane to intertidal position on west side of Dock Point. At 63 offset 300 feet northwest along bedding plane trough abandoned stone quarry. Bedding planes in quarry possess remarkable sole marks: 36 groove casts, 23 flute casts, 2 parting lineations, and 1 frondescent mark were measured; paleocurrents range from S. 50° W. to N. 65° W. Lith sample WBH-113 at 40 feet. Lith sample WBH-112 in interval 20-0.

Contact: De Courcy Formation, Tongue 3 (Kd_3) and Cedar District Formation, upper member; sharp and planar, picked at base of sandstone bed where beds increase abruptly to 3 feet and greater thickness. In gross aspect the contact is intercalated and gradational over 30 feet or less by an increase in sandstone thickness and decrease in mudstone thickness.

Initial point: about 50 feet above high-tide mark on the northeast side of Vesuvius Bay and southwest side of Dock Point, about 1150 feet northwest of Vesuvius Ferry Landing; bearings to the ferry landing and sharp point on west side of Vesuvius Bay are S. 24° E. and S. 02° E., respectively. Attitude is N. 63° W., 73° N.; proceed N. 27° E., up section.

Measured Section K-L, Northumberland Formation, De Courcy Formation, and Cedar District Formation.

Section K-L, encompassing intertonguing Northumberland, De Courcy, and Cedar District Formations, was measured on the west limb of the Trincomali Anticline from the west shore of Southey Bay to a point about 1400 feet south of Stone Cutters Bay on the west shore of the north tip of Saltspring Island. Straight, northwest-trending sections of coastline are dip slopes of resistant De Courcy Formation sandstone. Stone Cutters Bay and smaller northwest-trending inlets mark the sites of the finer-grained, more thinly bedded, and less resistant Northumberland and Cedar District Formations. Present are three De Courcy sandstone tongues and Cedar District and Northumberland, Formation mudstone and sandstone tongues which total 815 feet in thickness.

Terminal point L: within the De Courcy Formation (Kd_4) about 50 feet below the Northumberland Formation at the waterline (at a plus 1.5 foot tidal level) on the prominent sandstone dip slope at a point 1400 feet south of Stone Cutters Bay. Bearings to the south tips of Idol and Kuper Islands are S. 43° W. and N. 71° W., respectively.

Contact at L: Northumberland Formation over De Courcy Formation (Kd_4) is covered by water, but 200 feet to the south a near vertical fault which trends N. 30° W., south side up, offsets the contact to the southwest where it appears gradational over about 100 feet with an overall upward decrease in sandstone bed thickness and increase in proportion of mudstone.

Interval (feet)	Description

De Courcy Formation, Tongue 4 (Kd_4) (thickness = 120 feet). Unit description: sandstone with rare thin siltstone and mudstone partings; forms prominent dip slope and the resistant rib at Stone Cutters Bay; honeycomb and cavernous weathering in the spray zone produces a well-defined notch.

Sandstone: yellowish gray (5Y 7/2), weathered; medium light gray (N6), fresh; bedding indistinct but locally marked by interlaminated coarse and fine sand populations, otherwise very thick-bedded; predominantly medium- to coarse-grained; moderately to poorly sorted; angular to subrounded; quartz, feldspar, muscovite, biotite, chert, rock fragments; calcareous; abundant subspherical calcareous concretions, to 5 feet diameter, weather out in relief and differ from enclosing sandstone only in resistance to weathering.

120-0	Sandstone as in unit description. This interval contains a few light gray micritic mudstone concretions and flat mudstone clasts to 1 foot long. At 100 offset 900 feet southeast along top of bed. At 80 offset 1200 feet southeast along top of bed. Lith sample WBH-129 at 80 feet.

Contact: De Courcy Formation, Tongue 4 (Kd_4) and Northumberland Formation, Tongue 1 (Kn_1); sharp and planar.

Northumberland Formation, Tongue 1 (Kn_1) (thickness = 75 feet).

75-0	Nonresistant interval is mostly covered by mudflats in Stone Cutters Bay. Limited outcrops are of repetitively very thinly-bedded sandstone, siltstone, and mudstone as in Kcd_1, below.

Contact: Northumberland Formation, Tongue 1 (Kn_1) and De Courcy Formation, Tongue 3 (Kd_3); covered.

Measured Section K-L, Northumberland, De Courcy and Cedar District Formations (cont.).

Interval (feet)	Description

De Courcy Formation, Tongue 3 (Kd_3) (thickness = 62 feet).

62-0	Sandstone and minor pebbly sandstone: resistant, forms the prominent dip slope of the east shore of Stone Cutters Bay; honeycomb and cavernous weathering in spray zone; light olive gray (5Y 6/1), weathered; medium light gray (N6), fresh; very thick-bedded; beds are separated by nonresistant intervals to 1 foot thick; some weathered surfaces show indistinct lamination and anastomosing parting which may be dish structure; noncalcareous; textures, mineralogy and concretions as in Kd_3, above. Locally small lenses about 3 inches thick and 2 feet wide contain very fine-pebbles, subangular to subrounded, of chert and quartz, matrix-supported. The few nonresistant, interbeds which are exposed consist of very fine- to fine-grained sandstones to 1 foot thick which are laminated and have a thinly platy parting, or possess undulating lamination (sinusoidal ripple lamination, wavelength 2 to 6 inches, amplitude 0.5 to 1.5 inches) and contorted lamination. Lith sample WBH-128 near top of interval. At 50 offset 600 feet southeast along top of bed. At 38 offset 1400 feet along top of bed to Stone Cutters Bay. At 31 offset 300 feet southeast along top of bed. Attitude is N. 43° W., 20° S.

Contact: De Courcy Formation, Tongue 3 (Kd_3) and Cedar District Formation, Tongue 1 (Kcd_1); sharp and remarkably planar. This contact is arbitrarily picked at the base of a 6 foot sandstone which is the lowest bed in the sequence of sandstones which forms the point 0.5 miles north of Stone Cutters Bay.

Cedar District Formation, Tongue 1 (Kcd_1) (thickness = 210 feet). Unit description: repetitively interbedded mudstone, siltstone, sandstone; this nonresistant interval forms a ribbed intertidal area; sequence is about 50 percent mudstone.

Mudstone: nonresistant; medium light gray (N6) to medium dary gray (N4), weathered and fresh; weathers into chips 0.25 by 0.25 inches; thin- to very thin-bedded, 1 inch to 1 foot; contains some discontinuous silty laminae.

Sandstone and siltstone: resistant thin rib-formers; light olive gray (5Y 6/1), weathered; medium light gray (N6), fresh; very thin- to thick-bedded, 1 inch to 4 feet, beds greater than 2 feet thick are rare; internally thinly laminated (about 16 per inch), contorted laminations present; commonly with thinly platy parting; slightly calcareous. Most sandstones are very fine-grained; rare beds greater than 2 feet thick are medium- to coarse-grained, thinly laminated and contain angular mudstone clasts. Sandstone and siltstone lower contacts are sharp and planar; upper contacts are mostly sharp and planar, although sharp and gently undulating contacts are present.

210-160	Transitional interval between Kd_2 and Kcd_1 is characterized by the occurrence of a few sandstone beds to 4 feet thick and a downsection increase in the proportion of mudstone. Lithologies as in unit description.

Measured Section K-L, Northumberland, De Courcy and Cedar District Formations (cont.).

Interval (feet)	Description
	137 is a medium-grained sandstone which is 4 feet thick.
119-95	Covered by beach sand in cove.
92-87	Covered by beach sand.
84-77	Covered by beach sand.
15-12	Stratum consists of a heterogeneous mixture of ripped-up siltstone and very fine-grained sandstone beds present as recumbent folds (wavelengths and amplitudes about 2 to 4 feet) and rolls in a matrix of mudstone andmedium-grained sandstone; no preferred direction of overfolding. It is a result of a subaqueous mass wasting event as shown by superjacent and subjacent undisturbed beds. The folded units acted as coherent plastic sheets a few inches thick and tens of feet long.
	At 0 offset 100 feet southeast along top of bed.

Contact: Cedar District Formation, Tongue 1 (Kcd_1) and De Courcy Formation, Southey Point member (Kd_3); sharp and planar.

De Courcy Formation, Southey Point member (Kd_3) (thickness = 348 feet). Unit description: sandstone with subordinate siltstone and mudstone.

Sandstone: resistant rib-formers; honeycomb weathering in the spray zone produces a waffle-like surface; light olive gray (5Y 6/1) to olive gray (5Y 4/1), weathered; medium light gray (N6), fresh; thin- to thick-bedded, 3 inches to 4 feet, mostly thick-bedded; generally structureless but locally multiple scour-and-fill and trough cross-bedding are present, trough sets are maximum of 10 feet long, 6 feet wide and 1 foot thick; they contain very fine pebbles of angular to subrounded chert which define the foreset laminae; interlamination of coarse and fine sand populations also occurs; fine- to very coarse-grained, medium sand is predominant; moderately sorted; angular to subrounded; quartz, feldspar, muscovite, biotite, dark rock fragments; calcareous; the thicker sandstone beds are commonly concretionary, subspherical calcareous concretions weather but in relief, to 3 feet diameter; sandstone lower contacts are sharp, planar and in the lower part of the unit have groove casts; upper contacts appear sharp and gently undulating (rippled?).

Mudstone and siltstone interbeds: often repetitively interbedded; nonresistant, mostly covered; light olive gray (5Y 6/1), weathered; very thin- to thin-bedded, 2 inches to 2 feet thick; noncalcareous. Some siltstone beds show cross-lamination, ripple profiles and small-scale truncations.

Interval (feet)	Description
348-252	Transitional sequence: strongly ribbed foreshore; predominantly sandstone ribs with several covered intervals to 5 feet thick. Sandstones: thin-bedded, 1 to 2 feet thick; with laminated and thinly platy, or rippled tops (sinsoidal lamination in cross section); locally, angular mudstone clasts are present; unfossiliferous except for abundant branching sand-filled organic burrows to 0.75 inches diameter. Covered intervals are probably mudstone and siltstone as in unit description. Contact sharp, planar.

Measured Section K-L, Northumberland, De Courcy and Cedar District Formations (cont.).

Interval (feet)	Description
252-228	Mostly covered by beach gravel; limited outcrops are repetitively very thinly bedded sandstone, siltstone and mudstone.
	Contact covered.
228-198	Thick-bedded sandstone as in unit description. Attitude is N. 41° W., 22° S.
	At 198 offset 200 feet southeast along top of bed.
	Contact covered.
198-194	Covered by beach sand.
	At 194 offset 250 feet southeast along top of bed.
194-184	Sandstone as in unit description.
184-170	Covered by beach sediment in small inlet.
170-30	Predominantly sandstone as in unit description: overall this interval shows as upward coarsening and thickening; non-resistant interbeds range from interlaminated mudstone, siltstone and very fine-grained sandstone to thinly laminated, argillaceous, siltstone to very fine-grained sandstone. Thinly laminated interbeds often possess a thinly platy to papery splitting property.
	At 166 a 2 inch thick coal seam crops out over 3 square yards on a bedding plane near the high-tide mark. The seam is a lens enclosed in about 10 inches of mudstone; the latter is overlain by 4 feet of sandstone which is laminated (interlaminated coarse and fine sand size populations), thinly trough cross-bedded, and contains multiple low-angle cross-bed sets.
	Mudstone and sandy mudstone: medium light gray (N6) to light brown (5YR 5/6), weathered; dark gray (N3), fresh; encloses coal seam; platy parting is locally developed as a result of fine carbonized plant debris and mica flakes on bedding planes; feldspar grains are deeply weathered (kaolinite). Abundant sand-filled organic burrows to 1 inch diameter are present and may account for the sandy mudstone (may have originally been interlaminated sandstone and mudstone).
	Coal sample WBH-125.
	At 155 offset 200 feet southeast along top of bed.
	At 140 are 2 large trough cross-bed sets as in unit description. Their axes trend N. 50° W. and S. 80° W., foresets are inclines to the west.
	At 140 attitude is N. 33° W., 16° S.
	At 134, top of sandstone rib appears to have interference ripples (wavelength 8 inches, amplitude 0.5 to 1.5 inches).

Measured Section K-L, Northumberland, De Courcy and Cedar District Formations (cont.).

Interval (feet)	Description
	At 90.5 is a 1 foot thick sandstone bed with papery parting and abundant organic burrows about 0.5 inches diameter on bedding planes (Thalassinoides?).
30-0	About 40 percent covered: exposures are sandstone and minor pebbly sandstone. Sandstone: resistant rib-formers; thin- to thick-bedded (2 to 3.5 feet); normally graded with thinly laminated and thinly platy to rippled tops, also present in a few beds is dish structure and probable pillar structure; fine- to very coarse-grained; moderately to poorly sorted; abundant argillaceous matrix. A few beds with distinctly very high content of matrix, contain fine- to very coarse pebbles, matrix-supported, angular to rounded, porphyritic volcanics, chert and light gray micritic mudstone concretions and flat angular mud rip-ups (the latter reach 2 feet length). These poorly sorted, argillaceous sandstones with dispersed and contorted clasts have sharp, planar soles with groove casts.
	Dish structure is well developed in one bed as small, overlapping plates (dishes) developed subparallel to bedding. They can be broken out as separate entities with convex lower surfaces marked by an argillaceous film. The dishes are 1 to 3 inches diameter and 0.25 to 0.5 inches thick and intermittently developed along the bed and replaced within 5 feet laterally by an anastomosing etched surface which does not break down into dishes. The etched surface pattern occurs in a few other beds. Probable pillar structure occurs in fine-grained top of a bed as narrow domal uplifts with 4 inches relief and 6 to 12 inches wavelength. The eroded upper surface of the bed with pillars, reveals circular regions (a few inches diameter) of quaquaversal lamination.
	Lith sample WBH-226 at 30.

Contact: within the De Courcy Formation (Kd_3), Southey Point member; probably close to base of member; very sharp and planar.

Initial point: base of lowest sandstone rib exposed above the waterline on the west side of Southey Bay at a tide of plus 3.0 feet. Initial point is about 8,000 feet north-northwest of terminal point which is opposite Idol Island. Bearing to navigation signal at Southey Point is N. 06° W. Attitude is N. 32° W., 13° S.; proceed S. 58° W., up section.

Measured Section M-N, Northumberland Formation.

Section M-N, encompassing the Northumberland Formation, was measured along the southwest shore of Welbury Bay between Welbury Point and the Long Harbor Ferry landing. Other steeply northeast-dipping units of the southwest limb of the Kulleet Syncline are the overlying Geoffrey Formation and underlying De Courcy Formation which form the northeast shore of Welbury Bay to Scott Point, and Welbury Point, respectively.

Terminal point N: base of 10 foot thick sandstone bed exposed at the northwest end of Welbury Bay on the north side of Scott Point Road at a point 200 feet west of the Long Harbor Ferry landing.

Contact at N: Geoffrey Formation and Northumberland Formation; sharp and conformable, 10 inches relief on load casts; basal Geoffrey Formation sandstone possesses bulbous load casts up to 2 feet diameter.

Interval (feet)	Description
Northumberland Formation (thickness = 1090 feet).	
1090-1088	Sandy, carbonaceous mudstone: nonresistant; medium dark gray (N4), fresh and weathered; locally laminated, with laminae defined by discontinuous siltstone and sandstone partings and lenses, concentrations of muscovite, coal flakes, carbonized wood, and rare deciduous leaves; sand grains occur suspended in mudstone matrix and in grain support with inter-granular mud matrix, fine- to coarse-grained, poorly sorted, angular to subangular, quartz, muscovite, feldspar, biotite. Attitude is N. 66° W., 66° N.
	Contact sharp, planar.
1088-1030.5	Silty mudstone with siltstone laminae: nonresistant; medium dark gray (N4), fresh and weathered: platy tendency upon initial weathering: platy tendency upon initial weathering, later breaks down into chips with dimensions of less than 0.5 inches; siltstone laminae up to 0.5 inches thick, are rhythmically spaced at intervals of 1 to 4 inches and disturbed by bioturbation. A 3-inch long piece of permineralized wood with Teredo-like borings was found. Attitude is N. 64° W., 65° N.
	Contact covered.
1030.5-650.5	Covered by pocket beach at back of Welbury Bay. This interval is on line with a probable shear zone which intersects the coastline on the east side of Long Harbor Ferry landing. Though no large offset of rock units is thought to exist, there is a disparity in attitude across the interval. Attitude for traverse is N. 70° W., 82° N.
	Contact covered.
650.5-465.5	Mostly covered. Interrupted outcrops are platy mudstone as at 465.5-365.5, below.
	Contact covered.

Measured Section M-N, Northumberland Formation (cont.).

Interval (feet)	Description
465.5-365.5	Mudstone with about 10 percent thin siltstone interbeds: nonresistant; exposed in abandoned quarry; medium gray (N5), weathered; mudstone is medium gray (N5) to grayish black (N2), fresh; siltstone is light gray (N7), fresh; platy tendency; siltstones are maximum of 2 inches thick, thinly laminated and cross-laminated, and rhythmically spaced at intervals of about 1 foot. Fossiliferous: paleontologic collection WBH-91-72; disarticulated Inoceramus (up to 8 inches in length) and a single planispiral ammonite 24 inches maximum diameter. At 365.5 offset 350 feet N. 60° W. to south wall of quarry. Contact covered by beach sediment on foreshore and brush at top of quarry.
365.5-230.5	Mudstone with about 20 percent rhythmic siltstone interbeds: semi-resistant, forms weakly ribbed foreshore; medium dark gray (N4), overall weathered; other colors as at 465.5-365.5, above; siltstone interbeds are predominantly less than 0.5 inches thick but pinch and swell along strike (ripples?), spaded at 4 to 6 inch intervals, abundant cross-lamination with foresets invariably inclined along strike to the northwest; present are discoidal calcareous concretions, color same as enclosing mudstone except for a few which are rusty-weathering, maximum dimensions 2 by 8 inches with long axes parallel to bedding; enclosing mudstone appears to bend around them.
230.5-158.5	Covered by beach sediment.
158.5-82	Mudstone with about 40 percent thin sandstone and siltstone beds and lenses: semi-resistant, forms weakly ribbed foreshore. Mudstone: nonresistant; medium dark gray (N4), weathered; platy; noncalcareous; contains thinly laminated siltstone lenses which are a maximum of 0.25 inches thick and 10 inches long; contains some calcareous concretions as interval 365.5-230.5, above. Lith sample of concretion: WBH-105 at 115 feet. Sandstone and siltstone interbeds: medium gray (N5), weathered; light gray (N7), fresh; subdued rib-formers; very thin beds to thin beds, maximum of 4 inches thick but rarely exceed 1 inch; internally laminated to thinly laminated, commonly with cross-laminated tops; sandstone is very fine-grained, well sorted, quartz, feldspar, black grains, non-calcareous; weathered contacts are sharp, planar and sometimes gently undulating with less than 0.5 inches relief. Multiple short northwest offsets along exposed stratification were employed in order to examine a fully exposed interval.

Measured Section M-N, Northumberland Formation (cont.).

Interval (feet)	Description
	Attitude is N. 60° W., 78° N.
	Contact sharp, planar.
82-0	Siltstone-sandstone and mudstone sequence: ribbed foreshore. Very fine-grained sandstone to siltstone beds: resistant rib-formers; medium gray (N5) to light olive gray (5Y 6/1), weathered; light gray (N7), fresh; very thin to thin beds, 0.5 to 20 inches thick; internally thinly laminated to laminated with rare contorted laminations (soft sediment fold is overturned to the northwest); weathered upper and lower contacts are sharp and planar. Lith sample at 10 feet: WBH-104. Silty mudstone interbeds: nonresistant; medium dark gray (N4), weathered; thinly laminated; mudstones mostly as partings less than 1 inch thick throughout interval but increase to a maximum of 16 inches near top.

Contact: Northumberland Formation and De Courcy Formation; gradational over 20 feet from very thick-bedded, cliff-forming De Courcy Formation sandstone to very thin-bedded sandstone, siltstone, mudstone of lower Northumberland Formation.

Initial point: top of highest thick-bedded sandstone which forms the face of a low seacliff at the northwest margin of a pocket beach 700 feet northwest of Welbury Point, Saltspring Island. Bearing to the Long Harbor Ferry landing is N. 10° W. Attitude is N. 60° W., 84° N.; proceed N. 30° E., upsection.

Measured Section O-P, Geoffrey Formation.

Section O-P was measured on the west limb of the Kulleet Syncline from a point about 1100 feet southeast of Parminter Point to the east side of Parminter Point. This coastline is steep and fully accessible only along the narrow high-tide bench. It is suggested that covered intervals of the upper and lower Geoffrey Formation represent mudstone and sandstone tongues of the Spray and Northumberland Formations, respectively. In this context, the Geoffrey Formation is divisible into a conglomeratic middle member (Kg_3) which separates intertonguing lower Geoffrey and upper Northumberland Formations (Kg_1, Kn_2, Kg_2, Kn_3) from intertonguing upper Geoffrey and lower Spray Formations (Ks_1, Kg_4, Ks_2, Kg_5, Ks_3, Kg_6, Ks_4, Kg_7).

Terminal point P: upper surface of the sandstone which forms the southwest shore of the small inlet on the east side of Parminter Point. Bearing to the south tip of Tent Is. N. 48° W.

Contact at P: Geoffrey Formation, Tongue 5 (Kg_5) and Spray Formation, Tongue 3 (Ks_3); covered by beach gravel in cove. Lack of attitude precludes further upsection measurement. Probably no more than 200 feet of section remain between the terminal point and syncline axis (based upon 20° average dip, the thickness is 170 feet). This unmeasured sequence consists of two covered intervals (Ks_3, Ks_4) which are separated and overlain by thick sandstones (Kg_6, Kg_7).

Interval (feet)	Description

Geoffrey Formation, Tongue 5 (Kg_5) (thickness = 30 feet). Unit description: sandstone to pebbly sandstone; resistant rib-former; yellowish gray (5Y 7/2), weathered; medium gray (N5) to medium light gray (N6), fresh; structureless; medium- to very coarse-grained with some matrix-supported very fine to fine pebbles; poorly sorted; angular; quartz, feldspar, rock fragments, muscovite, magnetite; conspicuous matrix; noncalcareous.

30-0	Sandstone as in unit description; contains some flat mudstone rip-ups.

Contact: Geoffrey Formation, Tongue 5 (Kg_5) and Spray Formation, Tongue 2 (Ks_2); poorly exposed because of differential erosion along this horizon, but is probably sharp and planar.

Spray Formation, Tongue 2 (Ks_2) (thickness = 12 feet).

12-10	Sandstone and mudstone sequence: nonresistant; poorly exposed. Sandstone: olive gray (5Y 4/1), weathered; thin-bedded (2 to 6 inches); individual beds are thinly laminated; very fine-grained; moderately well sorted; angular; quartz, muscovite; noncalcareous. Mudstone: medium dark gray (N4), weathered; contains considerable admixed silt. Lower and upper contacts appear sharp and planar.
10-0	Covered intertidal area.

Contact: Spray Formation, Tongue 2 (Ks_2) and Geoffrey Formation, Tongue 4 (Kg_4); covered.

Geoffrey Formation, Tongue 4 (Kg_4) (thickness = 25 feet).

25-0	Structureless sandstone to pebbly sandstone rib as in Kg_5.

Interval (feet)	Description

Contact: Geoffrey Formation, Tongue 4 (Kg_4) and Spray Formation, Tongue 1 (Ks_1); sharp and loaded, locally flame structures extend 3 inches into overlying bed. Flames are overturned to the northwest.

Spray Formation, Tongue 1 (Ks_1) (thickness = 22 feet).

22-20	Sandstone: nonresistant; olive gray (5Y 4/1), weathered; medium gray (N5), fresh; thinly laminated (14 per inch) throughout except for top 2 inches which consist of festoon trough cross-laminations, sets 1 to 1.5 inches thick, foreset laminae are inclined along strike to the northwest; fine-grained; moderately sorted; angular; quartz, muscovite; noncalcareous. Contact sharp and planar.
20-0	Mostly covered with interrupted outcrops of thin-bedded, thinly laminated, very fine-grained sandstone to siltstone. On the backshore lateral to the traverse the covered interbeds are mudstone.

Contact: Spray Formation, Tongue 1 (Ks_1) and Geoffrey Formation, middle member (Kg_3); covered.

Geoffrey Formation, middle member (Kg_3) (thickness = 234 feet). Unit description: sandstone to pebbly sandstone with lesser conglomerate; resistant cliff-former; honeycomb and cavernous weathering in spray zone creates a high-tide bench and overhanging visor or nips; yellowish gray (5Y 7/2), weathered; medium gray (N5) to medium light gray (N6), fresh; very thick-bedded; stratification obscure except where defined by conglomerate and pebbly sandstone lenses, zones of concretions and intraformational rip-ups, rarely by lamination and scour-and-fill; fine- to very coarse-grained, mostly medium- to coarse-grained, very fine to fine angular pebbles of quartz and chert in matrix support are common; poorly sorted; angular; quartz, feldspar, rock fragments, muscovite, magnetite; conspicuous intergranular matrix; noncalcareous.

234-219	Sandstone as in unit description; mostly structureless with some scour-and-fill; medium- to very coarse-grained. Contact sharp, gently undulating upon subjacent bed form.
219-182	Sandstone, pebbly sandstone, conglomerate. Sandstone: as in unit description; contains calcareous spherical concretions to 3 feet diameter; top 3 inches is normally graded; top 1 inch is very fine-grained, moderately sorted, thinly laminated, the parallel laminae are undulating (sinusoidal ripple lamination) and have a wavelength of 4 inches and amplitude of 1 inch. Conglomerate and pebbly sandstone: lenses are a maximum of 6 inches thick and 12 feet wide; very fine to medium pebbles; subangular to well rounded; lithologies as at 162-152. These lenses are a minor component of the interval. At 211 attitude is N. 52° W., 39° N.

Measured Section O-P, Geoffrey Formation (cont.).

Interval (feet)	Description
	Lith sample WBH-134 (concretion).
	Contact sharp, planar.
182-181	Intraformational conglomerate: clasts are medium dark gray (N4); maximum dimension 6 inches; flat and angular; mud rip-ups; grain-supported; medium- to coarse-grained sandstone matrix. Clasts lie roughly parallel to master stratification.
	Contact sharp, planar.
181-164	Sandstone as in unit description: unstratified; medium- to very coarse-grained. Present are spherical calcareous concretions 4 inches to 3 feet diameter which weather out in relief. Although present throughout this interval, the concretions tend to be concentrated in thin stratigraphic zones which parallel the overall stratification. They differ from the enclosing sandstone only in their resistance to weathering and erosion, and carbonate cement.
	At 64 offset 250 feet northwest along strike.
	Contact sharp, planar; is arbitrarily placed at top of highest pebble band.
164-162	Pebbly sandstone: sandstone colors, textures, mineralogy as in unit description; stratification is defined by discontinuous bands of very fine to fine pebbles; bands are maximum of 0.5 inches thick and spaced at 1 to 4 inch intervals; lithologies as at 162-152; interval contains a few flat clasts of thinly laminated very fine-grained sandstone.
	Contact sharp, planar.
162-152	Conglomerate: olive gray (5Y 5/1) to light olive gray (5Y 6/1), overall weathered aspect; unstratified; medium pebbles to small cobbles, coarse pebbles predominate (5 largest clasts have mean diameter of 3.75 inches); subrounded to well rounded; porphyritic volcanics, chert, quartz, granitics mudstone. Conglomerate channeled into underlying unit.
	At 152 offset 300 feet northwest along top of bed.
	Contact sharp, scour with 3 feet relief and 6 to 10 feet wavelength.
152-138	Sandstone and pebbly sandstone. Sandstone: as in unit description; contains lenticular pebbly sandstone channels and calcareous concretions. Pebbly sandstone: lenses are maximum of 3 feet thick and 20 feet wide; laminated to thin-bedded as defined by adjacent layers of different maximum pebble size; fine to medium pebbles; subangular to rounded; matrix-supported;

Measured Section O-P, Geoffrey Formation (cont.).

Interval (feet)	Description
	lithologies as at 162-152. A thin pebble lens passes through a concretion.
	At 138 offset 300 feet northwest along top of bed.
	Contact sharp, planar.
138-34	Sandstone as in unit description: with well-developed high-tide bench and visor; thickness is approximate because of structureless character and seacliffs which hamper measurement and prevent precise offsets. Interval contains abundant angular to subrounded mudstone and siltstone clasts to 2 inches maximum diameter, and some calcareous concretions 1 inch to 3 feet diameter. Attitude is N. 52° W., 47° N.
	At 34 offset 150 feet northwest along strike.
	Contact, gradational over 2 feet from conglomerate to pebbly sandstone to sandstone, is placed at top of pebbly sandstone.
34-28	Conglomerate: as at 162-152; fine to coarse pebbles and abundant mudstone clasts.
	Contact sharp, planar.
28-0	Sandstone as in unit description, except it is indistinctly laminated and top 2 feet shows scour-and-fill. Concretions and rare mud rip-ups have maximum dimensions of 2 feet and 1 inch, respectively.

Contact: Geoffrey Formation, middle member (Kg_3) and Northumberland Formation, Tongue 3 (Kn3); covered.

Northumberland Formation, Tongue 3 (Kn_3) (thickness = 65 feet).

65-0	Nonresistant interval is covered by mudflats in bay.

Contact: Northumberland Formation, Tongue 3 (Kn_3) and Geoffrey Formation, Tongue 2 (Kg_2); covered.

Geoffrey Formation, Tongue 2 (Kg_2) (thickness = 9 feet).

9-0	Structureless sandstone rib as in Kg_5.

Contact: Geoffrey Formation, Tongue 2 (Kg_2) and Northumberland Formation, Tongue 2 (Kn_2); covered.

Northumberland Formation, Tongue 2 (Kn_2) (thickness = 44 feet).

44-0	Nonresistant interval is covered by mudflats and gravel in bay.

Contact: Northumberland Formation, Tongue 2 (Kn_2) and Geoffrey Formation, Tongue 1 (Kg_1); covered.

Geoffrey Formation, Tongue 1 (Kg_1) (thickness = 20 feet).

Measured Section O-P, Geoffrey Formation (cont.).

Interval (feet)	Description
20-0	Structureless sandstone as Kg_5; cliff-former.

Contact: Geoffrey Formation, Tongue 1 (Kg_1) and Northumberland Formation, Main Member (Kn_1); covered by water of Stuart Channel.

Initial point: waterline at a tide of plus 0.5 feet on the southwest side of the point 1100 feet southwest of Parminter Point. Bearings to the south tip of Tent Island and the summit of Mount Erskine are N. 46° W. and S. 31° E., respectively. Attitude is N. 50° W., 59° N.; proceed N. 40° E., up section.

APPENDIX II

MODAL ANALYSES OF SANDSTONES

Appendix II. Modal Analyses of Comox Sandstone Samples.

Sample No.	2	12	39	40	48	62	49	71	123
VOIDS	-	-	-	1	8	1	2	2	2
CEMENT TOTAL	7	2	22	11	4	4	2	5	3
Calcite	-	-	22	-	-	-	T	-	-
Chlorite	6	T	-	11	-	-	2	-	-
Laumontite	-	-	T	-	4	3	T	4	3
Quartz	1	2	T	-	-	1	-	T	-
Iron-oxide	-	-	T	-	-	1	-	-	-
Prehnite	-	-	-	-	-	-	-	1	T
MATRIX TOTAL	3	1	-	-	1	1	2	4	T
Abund. diag.?	-	-	-	-	-	-	-	-	-
FRAMEWORK TOTAL	89	97	78	88	87	93	94	89	94
Quartz Total	10	24	-	30	32	41	23	39	33
NQ	2	2	-	19	16	14	15	26	19
UQ	1	4	-	8	12	19	3	9	9
PQ	4	10	-	3	4	8	4	4	4
Chert	3	8	-	T	-	-	1	-	1
Feldspar Total	17	16	-	17	16	25	19	27	27
Plagioclase	12	10	-	5	8	10	9	8	11
Orthoclase	-	-	-	T	T	1	-	1	2
Microcline	-	-	-	2	1	5	-	3	3
Undiffer.	5	6	-	10	7	9	10	15	11
Rock Frag Total	43	47	?	15	12	20	27	14	21
Volcanic VRF	-	4	-	-	2	T	1	T	1
Meta. MRF	43	43	-	14	4	18	22	12	13
Intrusive IRF	-	-	-	1	3	2	1	2	4
Undiffer.	-	-	-	-	3	-	3	-	3
Micas Total	7	5	T	2	3	3	15	5	2
Biotite	T	-	T	1	1	2	8	4	1
Muscovite	1	1	T	-	2	1	3	1	T
Chlorite	6	4	-	1	T	T	4	T	1
Fe-bearing Total	13	5	78	22	24	5	10	4	12
Epidote	11	5	1	5	5	2	[illegible]	4	2
Hornblende	-	-	T	8	4	-	-	T	6
Magnetite	T	T	71	1	-	-	-	-	-
Others	-	-	6	8	15	3	6	-	4
Others	T	-	-	1	-	-	-	-	-
Skeletal Cal.	T	-	-	-	-	-	-	-	-
Glauconite	-	-	-	-	-	-	-	-	-

Appendix II. Modal Analyses of Extension-Protection Sandstone Samples.

Sample No.	70	82	69	119	143	213	214	215
VOIDS	1	1	T	1	2	2	1	T
CEMENT TOTAL	6	15	4	4	5	4	1	2
Calcite	-	15	-	-	-	4	-	-
Chlorite	-	-	-	-	-	-	-	-
Laumontite	4	-	4	3	5	-	1	1
Quartz	T	-	-	1	-	-	-	1
Iron-oxide	2	-	-	-	-	-	-	-
Prehnite	-	-	-	-	-	-	-	-
MATRIX TOTAL	6	6	2	6	4	4	4	5
Abund. diag.?	-	-	-	-	-	-	-	-
FRAMEWORK TOTAL	87	78	94	89	89	90	94	93
Quartz Total	38	26	23	41	35	44	43	33
NQ	24	11	11	22	23	22	23	19
UQ	6	2	4	12	6	11	13	10
PQ	8	3	3	5	5	7	4	3
Chert	T	10	15	2	1	4	3	1
Feldspar Total	31	14	15	31	37	28	35	44
Plagioclase	10	2	4	12	11	10	9	11
Orthoclase	2	-	-	2	2	2	2	2
Microcline	-	-	-	-	-	-	-	-
Undiffer.	19	12	11	17	24	16	24	31
Rock Frag Total	11	28	38	12	13	9	11	7
Volcanic VRF	-	3	4	1	T	1	1	1
Meta MRF	6	4	17	7	9	3	5	2
Intrusive IRF	3	-	1	2	4	2	3	1
Undiffer.	2	21	16	2	T	3	2	3
Micas Total	5	6	4	3	4	7	4	7
Biotite	5	2	-	3	2	6	3	6
Muscovite	T	T	T	T	1	T	-	T
Chlorite	-	4	4	T	1	1	1	1
Fe-bearing Total	2	4	4	2	T	2	2	3
Epidote	1	T	1	1	T	1	1	1
Hornblende	-	-	-	-	-	-	-	-
Magnetite	-	T	-	-	-	-	T	1
Others	1	4	3	1	-	1	1	1
Others	-	-	-	-	-	-	-	-
Skeletal Cal.								
Glauconite								

Appendix II. Modal Analyses of Cedar District Sandstone Samples.

Sample No.	81	109	110	122	202	212
VOIDS	1	1	T	1	4	5
CEMENT TOTAL	2	2	5	T	10	8
Calcite	2	2	5	-	10	8
Chlorite	-	-	-	-	-	-
Laumontite	-	-	-	-	-	-
Quartz	T	-	-	T	-	-
Iron-oxide	-	-	-	-	-	-
Prehnite	-	-	-	-	-	-
MATRIX TOTAL	10	15	15	20	4	19
Abund. diag.?	+	?	?	-	-	-
FRAMEWORK TOTAL	87	82	80	79	86	68
Quartz Total	40	40	31	43	32	22
NQ	27	26	21	38	23	13
UQ	10	4	6	2	3	6
PQ	3	6	1	2	2	1
Chert	T	4	3	1	4	2
Feldspar Total	39	19	29	23	24	28
Plagioclase	33	11	11	7	9	14
Orthoclase	6	4	3	2	3	9
Microcline	-	-	-	-	-	-
Undiffer.	-	4	15	14	12	5
Rock Frag Total	2	22	13	8	21	10
Volcanic VRF	-	10	5	3	8	1
Meta MRF	2	7	4	4	7	5
Intrusive IRF	-	1	1	1	2	4
Undiffer.	-	4	3	-	4	T
Micas Total	5	2	4	4	5	8
Biotite	3	-	2	2	3	4
Muscovite	1	T	-	1	1	2
Chlorite	1	2	2	1	1	2
Fe-bearing Total	2	T	3	1	-	-
Epidote	T	-	-	T	-	-
Hornblende	-	-	-	-	-	-
Magnetite	-	T	-	-	-	T
Others	1	-	3	1	-	-
Others	-	-	T	-	T	-
Skeletal Cal.	-	-	T	-	-	-
Glauconite	-	-	-	-	T	-

Appendix II. Modal Analyses of De Courcy Sandstone Samples.

Sample No.	106	113	114	116C	124	128	130	129
VOIDS	4	13	1	6	2	-	2	-
CEMENT TOTAL	3	-	4	2	10	8	-	37
Calcite	-	-	-	-	-	8	-	37
Chlorite	-	-	-	-	-	T	?	-
Laumontite	-	-	-	T	10	-	-	-
Quartz	1	-	4	1	-	-	-	-
Iron-oxide	2	-	-	1	-	-	-	-
Prehnite	-	-	-	-	-	-	-	-
MATRIX TOTAL	7	6	3	1	3	15	11	3
Abund. diag.?	-	-	-	-	-	+	+	-
FRAMEWORK TOTAL	86	81	92	91	85	77	87	60
Quartz Total	40	38	39	39	36	37	40	23
NQ	33	30	33	23	28	31	30	17
UQ	4	4	6	5	5	4	4	1
PQ	1	2	T	4	2	1	3	2
Chert	2	2	-	7	1	1	3	3
Feldspar Total	33	32	40	28	35	28	29	17
Plagioclase	7	10	5	11	12	12	9	9
Orthoclase	4	3	2	4	3	2	2	6
Microcline	-	-	-	T	-	-	T	-
Undiffer.	22	19	33	13	20	14	18	2
Rock Frag Total	8	6	6	20	6	8	15	11
Volcanic VRF	1	1	1	9	1	5	6	6
Meta MRF	3	2	1	7	1	2	2	4
Intrusive IRF	2	2	1	4	2	1	6	-
Undiffer.	2	1	3	1	2	T	1	1
Mica Total	4	5	7	3	8	3	2	6
Biotite	3	4	5	2	5	2	1	3
Muscovite	1	1	2	1	2	1	1	1
Chlorite	-	-	-	T	1	-	-	2
Fe-bearing Total	1	T	-	T	T	1	1	2
Epidote	T	-	-	-	T	-	T	T
Hornblende	-	-	-	-	-	-	-	-
Magnetite	-	-	-	-	-	T	-	1
Others	1	T	-	T	-	1	1	1
Others	-	-	-	-	-	-	-	1
Skeletal Cal.								T
Glauconite	-	-	-	-	-	-	-	1
Apatite								

Appendix II. Modal Analyses of De Courcy Sandstone Samples.

Sample No.	206	208	207	216	220	219	224	226	227
VOIDS	5	T	1	2	6	4	1	2	-
CEMENT TOTAL	-	T	2	T	1	T	1	1	24
Calcite	-	-	2	-	1	T	-	-	24
Chlorite	-	T	-	-	-	-	-	-	-
Laumontite	-	-	-	-	-	T	1	-	-
Quartz	-	-	-	T	-	-	-	1	-
Iron-oxide	-	-	-	-	-	-	-	-	-
Prehnite	-	-	-	-	-	-	-	-	-
MATRIX TOTAL	6	12	14	10	11	6	5	11	9
Abund. diag.?	-	+	+	+	-	-	-	+	+
FRAMEWORK TOTAL	89	88	83	88	82	90	94	86	67
Quartz Total	28	43	33	38	33	41	50	30	34
NQ	23	24	23	33	23	33	33	17	25
UQ	3	8	6	5	5	6	12	11	3
PQ	1	4	1	T	3	1	3	1	6
Chert	1	7	3	T	2	1	2	1	-
Feldspar Total	33	29	31	37	29	37	28	32	20
Plagioclase	9	8	13	6	13	4	6	9	8
Orthoclase	1	5	2	3	3	3	3	1	3
Microcline	-	T	-	T	1	-	T	T	-
Undiffer.	23	16	16	28	12	30	19	22	9
Rock Frag Total	18	11	11	7	18	6	10	14	9
Volcanic VRF	5	5	6	5	11	3	3	5	3
Meta MRF	3	3	2	1	3	1	1	1	2
Intrusive IRF	T	2	1	1	2	1	2	1	1
Undiffer.	10	1	2	-	2	1	4	7	3
Micas Total	9	5	6	5	1	4	3	8	4
Biotite	5	3	5	3	T	3	2	6	1
Muscovite	1	1	1	2	1	1	1	T	-
Chlorite	3	1	T	T	T	T	T	2	3
Fe-bearing Total	1	T	2	1	1	2	2	1	T
Epidote	-	-	-	-	T	T	T	-	-
Hornblende	-	-	-	-	-	-	-	-	-
Magnetite	1	T	-	T	-	T	-	-	T
Others	T	-	2	1	1	2	2	1	-
Others	-	-	-	-	-	-	-	-	-
Skeletal Cal.									
Glauconite									
Apatite									

Appendix II. Modal Analyses of Geoffrey Sandstone Samples.

Sample No.	101	131	132	134	210	211	218	221
VOIDS	3	-	1	-	9	T	2	2
CEMENT TOTAL	T	23	T	20	T	T	T	1
Calcite	-	23	T	20	-	T	-	1
Chlorite	-	-	-	-	-	-	-	-
Laumontite	-	-	-	-	-	T	-	-
Quartz	-	-	-	-	T	-	T	-
Iron-oxide	-	-	-	-	-	-	-	-
Prehnite	-	-	-	-	-	-	-	-
MATRIX TOTAL	12	-	11	7	6	14	8	16
Abund. diag.?	+	-	+	-	-	+	-	+
FRAMEWORK TOTAL	85	77	88	73	85	86	90	81
Quartz Total	28	32	34	36	38	27	44	34
NQ	23	24	22	30	25	18	36	27
UQ	4	3	8	3	7	5	3	5
PQ	1	2	3	1	3	2	3	2
Chert	-	3	1	2	3	2	2	T
Feldspar Total	36	19	28	19	26	40	28	26
Plagioclase	16	8	6	6	11	26	10	10
Orthoclase	2	1	3	2	3	11	3	3
Microcline	T	-	-	-	T	-	T	-
Undiffer.	18	10	19	11	12	3	15	13
Rock Frag Total	14	20	22	15	15	12	13	14
Volcanic VRF	3	11	12	9	4	3	2	7
Meta MRF	6	2	3	4	5	4	5	3
Intrusive IRF	4	4	4	1	2	4	2	2
Undiffer.	1	3	3	1	4	1	4	2
Micas Total	6	3	3	1	5	5	5	6
Biotite	4	2	2	1	5	2	3	5
Muscovite	1	1	T	T	T	1	1	1
Chlorite	1	T	1	T	T	2	1	T
Fe-bearing Total	1	3	T	2	T	2	T	1
Epidote	T	-	T	-	T	-	T	T
Hornblende	-	2	T	1	-	-	-	T
Magnetite	-	1	-	T	-	2	T	-
Others	1	T	T	1	-	-	-	-
Others	-	-	-	-	-	T	-	T
Skeletal Cal.						-		-
Glauconite						-		-
Apatite						T		T

Appendix II. Modal Analyses of Geoffrey Sandstone Samples.

Sample No.	222	223	234	235
VOIDS	1	-	-	-
CEMENT TOTAL	4	-	23	-
Calcite	-	-	23	-
Chlorite	-	-	-	-
Laumontite	4	-	-	-
Quartz	-	-	-	-
Iron-oxide	-	-	-	-
Prehnite	-	-	-	-
MATRIX TOTAL	6	17	3	10
Abund. diag.?	+	+	-	+
FRAMEWORK TOTAL	89	83	74	90
Quartz Total	34	32	37	24
NQ	29	26	34	20
UQ	3	2	1	2
PQ	1	2	1	1
Chert	1	2	1	1
Feldspar Total	29	29	17	24
Plagioclase	20	19	8	14
Orthoclase	4	4	1	T
Microcline	-	-	-	-
Undiffer.	5	6	8	10
Rock Frag Total	21	17	11	28
Volcanic VRF	11	12	7	25
Meta MRF	3	3	3	3
Intrusive IRF	3	2	1	T
Undiffer.	4	-	T	-
Micas Total	3	5	6	4
Biotite	1	2	4	3
Muscovite	1	2	1	1
Chlorite	1	1	1	-
Fe-bearing Total	1	T	3	9
Epidote	T	-	-	T
Hornblende	T	-	1	5
Magnetite	1	-	1	2
Others	-	T	1	2
Others	-	T	-	-
Skeletal Cal.	-	-	-	-
Glauconite	-	-	-	-
Apatite	-	T	-	-

APPENDIX III

TEXTURAL PARAMETERS OF SELECTED SANDSTONES

Appendix III. Textural Parameters of Selected Sandstones.

Sample Number	Stratigraphic Unit	Grain size	Sorting	Roundness (Powers, 1953)	Maturity (Folk, 1951)
2	Comox, Beaver Point	fine to coarse	moderate	A - a	submature
5	Comox, Beaver Point	fine to medium	moderate to well	A	submature
12	Comox, Yeo Point	medium to coarse	well	a - r	mature
24	Comox, Eleanor Point	very fine to fine	moderate	A	immature
49	Comox, middle member	medium to coarse	well	A - r	submature
39	Comox, upper member	very fine to fine	very well	A - a	mature
40	Comox, upper member	medium to coarse	moderate to well	A - r	mature
48	Comox, upper member	moderate to coarse	well	a - r	mature
62	Comox, upper member	medium to very coarse	moderate to well	A - r	submature
71	Comox, upper member	medium to coarse	well	A - r	submature to mature
123	Comox, upper member	medium to very coarse	well	A - r	submature to mature
69	Cape Keppel	medium to coarse	well	A - r	mature
70	Middle Extension-Protection	fine to very coarse	poor to moderate	A	immature
82	Middle Extension-Protection	medium	well	A - r	immature
83	Middle Extension-Protection	fine to very coarse	moderate	A - a	immature
119	Middle Extension-Protection	fine to coarse	moderate	A - a	submature
143	Middle Extension-Protection	fine to coarse	moderate	A - a	submature
215	Upper Extension-Protection	medium	well	a	submature
213	Ganges Hbr. member	fine to coarse	moderate to well	a - r	submature
214	Ganges Hbr. member	medium	well	a	mature
81	Lower Cedar District	fine to medium	moderate	A - a	immature
108	Upper Cedar District	very fine to fine	very well	A - a	submature to mature
109	Upper Cedar District	medium to very coarse	moderate	a - r	immature
110	Upper Cedar District	medium	moderate	A	immature
122	Upper Cedar District	fine to very coarse	poor	A - a	immature
127	Upper Cedar District	fine to pebbles	poor	A - r	immature
202	Upper Cedar District	medium to coarse	well	a	submature
212	Upper Cedar District	medium to very coarse	moderate	A - a	immature
225	Upper Cedar District	very fine to fine	very well	A - a	submature

Appendix III. Continued.

Sample Number	Stratigraphic Unit	Grain Size	Sorting	Roundness (Powers, 1953)	Maturity (Folk, 1951)
106	De Courcy Tongue 1	fine to medium	moderate	A - a	immature
114	De Courcy Tongue 1	fine to medium	well	A - a	submature
116C	De Courcy Tongue 1	medium to very coarse	moderate to well	A - a	submature
224	De Courcy Tongue 1	medium to coarse	moderate	A - a	immature
226	De Courcy Tongue 2	fine to coarse	moderate	A - r	immature
227	De Courcy Tongue 2	fine to coarse	moderate	a - r	immature ?
113	De Courcy Tongue 3	medium to coarse	moderate	a	immature
124	De Courcy Tongue 3	fine to coarse	moderate	A - a	submature
128	De Courcy Tongue 3	fine to very coarse	poor to moderate	a - r	immature
207	De Courcy Tongue 3	fine to coarse	poor to moderate	a	immature
208	De Courcy Tongue 3	fine to very coarse	poor to moderate	A - r	immature
216	De Courcy Tongue 3	fine to coarse	moderate	a	immature
220	De Courcy Tongue 3	fine to medium	moderate	A - r	immature
129	De Courcy Tongue 4	fine to coarse	moderate	a ?	submature
130	De Courcy Tongue 4	fine to very coarse	poor	a	immature
104	Northumberland Formation	fine	very well	A - a	submature to mature
101	Lower Geoffrey	fine to coarse	poor to moderate	A - a	immature
131	Lower Geoffrey	fine to very coarse	moderate	A - a	submature
132	Lower Geoffrey	medium to coarse	moderate	A	immature
210	Lower Geoffrey	medium to coarse	moderate	A - a	immature
211	Lower Geoffrey	fine to very coarse	poor to moderate	A - a	immature
218	Lower Geoffrey	fine to coarse	poor to moderate	a	immature
221	Lower Geoffrey	fine to coarse	poor	A - r	immature
134	Middle Geoffrey	fine to very coarse	poor	A - r	immature
222	Upper Geoffrey	medium to coarse	moderate	a	immature
223	Upper Geoffrey	fine to very coarse	poor	A - r	immature
234	Upper Geoffrey	fine to coarse	poor to moderate	A - a	submature
235	Upper Geoffrey	fine to coarse	moderate	A - a	immature

A = angular r = subrounded a = subangular

APPENDIX IV

POTASSIUM FELDSPAR ABUNDANCE
PERCENT OF YELLOW-STAINED (SODIUM COBALTINITRITE) GRAINS ON SANDSTONE BILLETS

Appendix IV. Percent of Yellow-Stained Grains on Sandstone Billets. Minimum 400 counts per Sample.

Sample	Stratigraphic Unit		Percent
	Comox Formation		$\bar{X}$= 4.2
2	Beaver Point outlier		1
12	Yeo Point outlier		2
49	middle member	less than	1
62	upper member		5
71	upper member		7
48	upper member		5
40	upper member		4
123	upper member		9
	Extension-Protection Formation		$\bar{X}$=8.6
119	middle member		14
143	middle member		11
70	middle member		15
82	middle member		0
69	Cape Keppel outlier		0
81	lower Cedar District Formation		7
215	upper member		7
214	Ganges Harbor member		14.5
	De Courcy and upper Cedar District Formations		$\bar{X}$=10.3
224	De Courcy Tongue 1		17
114	De Courcy Tongue 1		16
116C	De Courcy Tongue 1		13
106	De Courcy Tongue 1		17
206	upper Cedar District		7.5
212	upper Cedar District		8
109	upper Cedar District		10
122	upper Cedar District		11
225	upper Cedar District		4.5
226	De Courcy Tongue 2		11
227	De Courcy Tongue 2		5
202	upper Cedar District		9.5
110	upper Cedar District		6
219	upper Cedar District		12
207	De Courcy Tongue 3		8
128	De Courcy Tongue 3		8
216	De Courcy Tongue 3		16
220	De Courcy Tongue 3		9
113	De Courcy Tongue 3		12.5
208	De Courcy Tongue 3		13.5
124	De Courcy Tongue 3		8
129	De Courcy Tongue 4		6
130	De Courcy Tongue 4		9

Appendix IV. Continued.

Sample	Stratigraphic Unit	Percent
	Geoffrey Formation	$\bar{X}$=10.6
101	lower member	8
221	lower member	7.5
210	lower member	12
218	lower member	12.5
211	lower member	7
132	lower member	11
131	lower member	8
134	middle member	11.5
222	upper member	16.5
234	upper member	5
235	upper member	8
223	upper member	20

APPENDIX V

MINERALOGY OF HEAVY MINERAL GRAIN MOUNTS

Appendix V. Heavy Mineral Grain Mounts of 3-4Ø Fractions.

Samples	H-123	H-2	H-4	H-3	H-1
Minerals					
Green Hornblende	VA	-	-	R	VA
Actinolite	VA	-	-	-	-
Lamprobolite	-	-	R	-	R
Augite	R	-	-	-	R
Epidote	A	A	R	R	A
Clinozoisite	R	-	-	R	R
Green Biotite	-	-	-	A	-
Brown Biotite	-	C	A	VA	R
Muscovite	-	R	-	-	-
Chlorite (including Penninite)	-	-	R	-	-
Apatite	R	C	VA	VA	A
Tourmaline (Brown)	-	R	-	R	-
Schorlite (Blue to Gray)	-	-	R	R	-
Euhedral Zircon	-	R	R	R	R
Angular Purple Zircon	-	-	R	-	-
Sphene	R	C	R	R	C
Clear Garnet	-	C	C	A	C
Grossularite	R	-	-	A	-
Purple Garnet	-	-	-	R	R
Salmon Garnet	-	-	-	R	R
Rutile	-	-	-	R	-
Hematite	-	C	R	-	R
Leucoxene	-	-	VA	-	-
Black Metallic Opaque	-	-	R	-	C

Appendix V. (Continued). Location of Sandstone Samples Selected for Heavy Mineral Grain Mounts of 3-4Ø Fractions.

SAMPLE	
H-123	Comox Formation upper sandstone member. Fresh cliff exposure. Cuesta anti-dip slope, 5/8 mile E. of Lake Maxwell; NW. 1/4, NW. 1/4 Section 84.
39	Comox Formation upper sandstone member. Cuesta anti-dip slope 0.5 miles N. of Lake Maxwell, Lot 13.
H-2	Extension-Protection Formation, middle member. Recently blasted pebbly sandstone exposed on NE. side of gravel road 1/4 mile NE. Cusheon Lake; SE. 1/4, NE. 1/4 Section 86.
H-3	Basal De Courcy Tongue 3. Weathered sandstone rubbed from underside of cavernous overhang on seacliff. 3/16 miles NW. of Welbury, Lot 1.
H-4	De Courcy Tongue 2, Southey Point member. Weathered sandstone rubbed from base of cavernous overhang at backshore. East side of Southey Bay, 1/8 mile SE. of navigation signal.
H-I	Geoffrey Formation middle member. Weathered sandstone rubbed from underside of cavernous overhang on seacliff. W. side of Parminter Point, W. end Lot 7.

VA = very abundant

A = abundant

C = common

R = rare

APPENDIX VI

MINERALOGY OF GRAIN MOUNTS FROM MAGNETIC SEPARATION OF COMOX FORMATION BEACH PLACER

Appendix VI. Mineralogy of Grain Mounts from Magnetic Separation of Comox Formation Sample 39, Beach Placer. VA = very abundant, A = abundant, C = common, R = rare.

Hand magnet fraction. 43 weight percent of 3-4Ø fraction.

VA Magnetite, ilmenite?
A Leucoxene
C Chromite?
C Euhedral zircon
C Epidote
C Hematite
R Pink garnet
R Amber garnet
R Purple garnet
R Hypersthene
R Sphene

Subsample A. Magnetic at 0.4 Amps, 25° forward slope and 17° side slope.

VA Ilmenite
C Leucoxene
C Hematite
C Chromite?
R Hypersthene, zircon, garnet

Subsample B. Magnetic at 0.8 Amps, 25° forward slope and 17° side slope.

VA Epidote
A Leucoxene and Ilmenite
A Green hornblende
C Garnet (pale violet, purple pleochroic, amber, pale green)
C Chromite?
R Hematite

Subsample C. Magnetic at 1.2 Amps, 27° Forward slope and 17° side slope.

VA Epidote
A Green hornblende
C Garnet (clear, amber, pale green, violet)
R Clinopyroxene
R Zoisite
R Sphene

Subsample D. Nonmagnetic at 1.2 Amps, 27° forward slope and 17° side slope.

VA Euhedral zircon
A Sphene
C Leucoxene
C Angular zircon
R Rounded zircon
R Hematite
R Rutile
R Monazite

APPENDIX VII

CLAY MINERALOGY OF SELECTED MUDSTONE SAMPLES

Appendix VII. Clay Mineralogy of Selected Mudstone Samples. X = abundant, M = minor, - = absent, ? = questionable occurrence.

Sample	Mica	Chlorite	Montmorillionite	Kaolinite	Chloritic Intergrade	Reg. Interstrat. 24Å
Comox Formation						
77	M	X	-	X	X	-
Haslam Formation						
H-1	X	X	-	X	X	M
H-73	X	X	-	X	X	?
H-74	X	X	M	X	X	X
H-75	X	X	M	?	X	M
De Courcy Formation						
135	?	?	-	?	?	-
Northumberland Formation						
N-1	X	X	X	X	-	-
102	X	X	X	X	M	M
Geoffrey Formation						
103	X	M	X	X	X	-
Spray Formation						
S-1	X	X	X	X	-	-

Appendix VII (Continued). Location of Mudstone Samples Selected for Clay Mineral Identification.

SAMPLE	
77	Comox Formation middle member, carbonaceous sandy mudstone. Road cut on Cranberry Road 3/8 mile NE. of Lake Maxwell; N. 1/2, E. 1/2, E. 1/2 Lot 36.
H-1	Uppermost Haslam Formation, marine silty mudstone. Base of sea cliff on north side of mouth of Cusheon Creek; NE. 1/4 Section 76.
H-73	Upper Haslam Formation, marine mudstone. Quarry in NW. corner Lot 11 on Cranberry Road.
H-74	Upper Haslam Formation, marine mudstone. Excavation at intersection of Blackburn Road and Ganges-Fulford Highway; NE. 1/4, NW. 1/4 Section 86.
H-75	Upper Haslam Formation, marine mudstone. Twa landfill excavation about 1/2 mile NW. of Blackburn Lake; E. end of Lot 14.
135	De Courcy Formation, Tongue 3, siltstone bed in Lower part. 1/4 mile SE. of Dock Point.
N-1	Middle of Northumberland Formation, marine mudstone. Excavation on east side of Sunset Drive, Lot 3.
102	Uppermost Northumberland Formation, carbonaceous and sandy marine? mudstone. Road cut on west side of Scott Road at back of Welbury Bay; Lot 1.
103	Geoffrey Formation, lower sandstone member; silty marine mudstone about 200 feet above base of formation. Road cut on west side of Scott Road at back of Welburry Bay and west side of Long Harbor ferry landing, Lot 1.
S-1	Lower Spray Formation, silty mudstone. Shore platform on NE. shore Long Harbor about 3/8 mile NW. of Long Harbor ferry landing.