AN ABSTRACT OF THE THESIS OF

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Title: GEOLOGY OF THE DUKE POINT-KULLEET BAY AREA, VANCOUVER ISLAND, B.C.

Abstract approved: Redacted for privacy
Dr. Keith F. Oles

The Duke Point-Kulleet Bay area is located on the southeast coast of Vancouver Island, B.C., approximately 60 miles northwest of Victoria, B.C. and 25 miles west, across the Strait of Georgia, from Vancouver, B.C. Approximately 2500 feet of Late Cretaceous sedimentary rocks of the Nanaimo Group are exposed within the area of investigation.

The rocks were deposited in the Nanaimo Basin by a series of east and northeast flowing streams and rivers carrying sediments from the pre-Pennsylvanian Sicker Group volcanics, metavolcanics, argillites and quartzites, the Late Triassic-Early Jurassic Vancouver Group volcanics, limestones, argillites and greywackes, and the Middle Jurassic granodiorite-gabbro Island Intrusions.

Formations within the area are: 1) the Cedar District, mainly marine mudstones with limy concretions and sandstone dikes, and

2) the De Courcy, mainly fluvial to shallow marine arkosic wackes, exhibiting honeycomb weathering and containing concretions and minor conglomerate.

During the Late Cretaceous and Tertiary the rocks were differentially uplifted and folded and faulted into a northwest-southeast trending belt. The possibility of later episodes of diastrophism exists. Two Pleistocene glacial epochs scoured the rocks and left till deposits behind during their retreats.

Coal was mined extensively in the Nanaimo Basin from the 1850's to the 1940's and 1950's, but is no longer an economic commodity. Building stone and sand and gravel have been quarried for local use. Petroleum companies have investigated the area, but the results of their exploration have not been made public.

Geology of the Duke Point-Kulleet Bay Area, Vancouver Island, B. C.

by

Richard Wyman Rinne

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GEOLOGY OF THE DUKE POINT-KULLEET BAY AREA, VANCOUVER ISLAND, B. C.

INTRODUCTION

Location and Accessibility

The Duke Point-Kulleet Bay area is located 65 miles northeast of Victoria, B. C. on the northeast coast of Vancouver Island and 25 miles west across the Strait of Georgia from Vancouver, B. C. Duke Point is three miles S. 68° E. from Nanaimo, B. C. and lies adjacent to the southwest shore of Gabriola Island (see Index Map, Figure 1). Kulleet Bay is 9-1/2 miles S. 30° E. from Duke Point. The area of study extends three to five miles inland, depending on the amount and kind of exposures.

The bulk of the geologic effort was accomplished on the coast between Duke Point and Kulleet Bay because of the nearly continuous exposures in sea cliffs and along wave-cut platforms. Two of the three measured and described sections are on the coast, and they comprise approximately three of the 12.5 miles of rock exposed.

This area is the site of past extensive logging and coal mining operations and is now undergoing a land development boom, making most of the region accessible by secondary roads. Much of the mapping was done on private property, whose residents usually were most cooperative. Only two individuals denied access to their land.

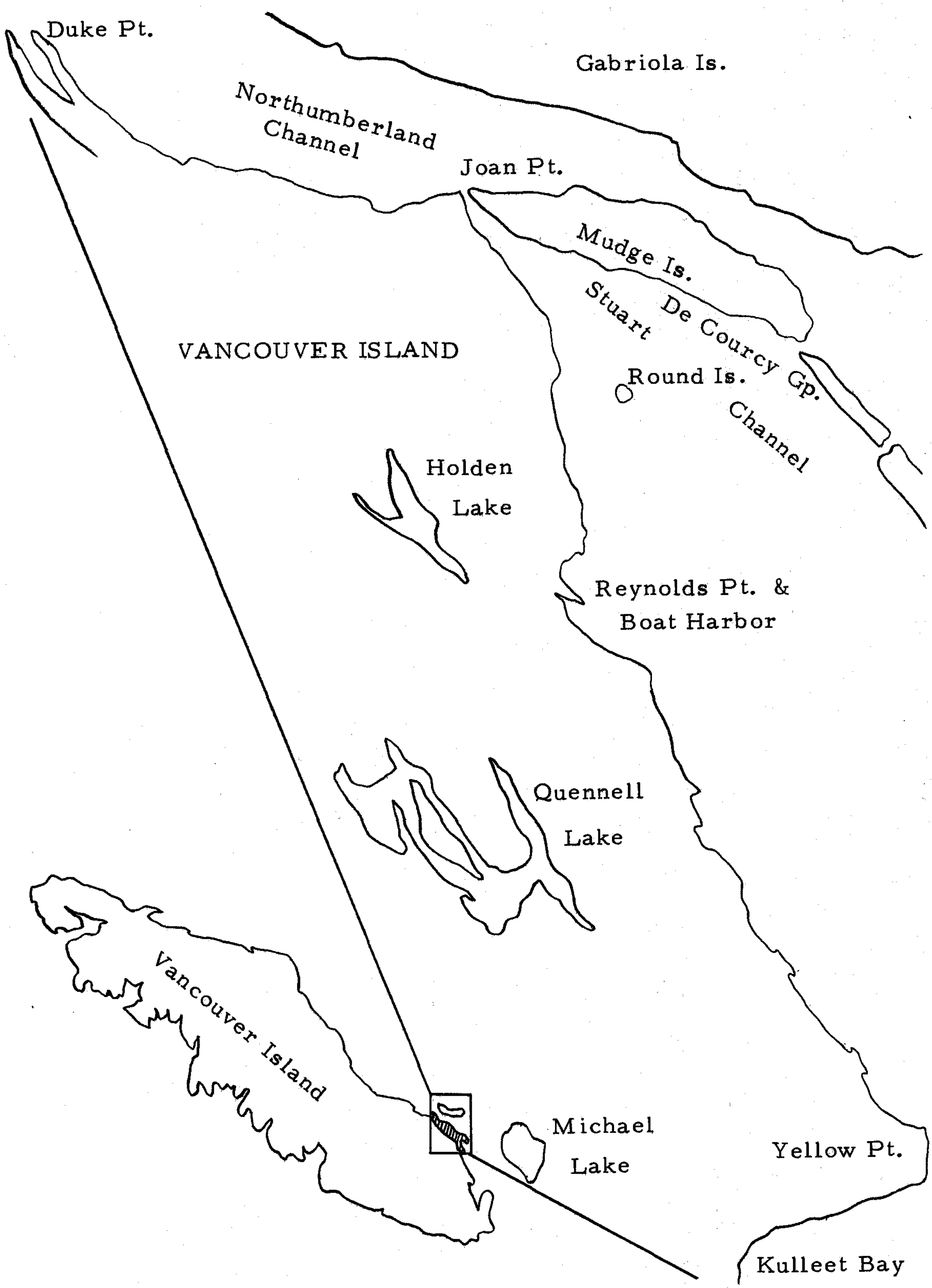


Figure 1. Index map of thesis area and Vancouver Island (inset) with thesis area hatched.

Purposes and Methods of Investigation

The primary purposes of the field and laboratory studies were: 1) to produce a detailed geologic map of the structures and stratigraphy, 2) to provide a description and analysis of the lithology, 3) to make a paleogeographic study with respect to paleocurrents, paleoslopes and depositional environments of this part of the Nanaimo Basin, and 4) to synthesize all collected data into a Master of Science thesis in geology.

Field work began June 10, 1971, and was terminated August 20, 1971. Field observations were plotted on low altitude (1:18,000) aerial photographs purchased from the Air Survey Division, Survey and Mapping Branch, Department of Lands, Forests and Water Resources, Victoria, B.C. Photo interpretation was conducted in the field using a pocket stereoscope. The data were transferred to a Survey and Mapping Branch topographic map (scale 1:50,000) and subsequently to a geologic map (scale 1:20,000).

Stratigraphic sections were measured in the field using a five-foot Jacob's staff and a Brunton compass. Field descriptions utilized a 10-power hand lens, dilute hydrochloric acid, the G.S.A. Rock-Color Chart, the Wentworth grain-size scale and McKee and Weir's "Terminology for Stratification and Cross-stratification in Sedimentary Rocks." Seventeen thin-sections were examined petrographically to supplement and confirm field observations and Gilbert's (1954) classification was used to describe sandstones.

Previous Work

Most of the early geologic investigation in the area was spurred by the abundance of coal in the Nanaimo region. Early mapping was done by Richardson (1872), Bancroft (1913), and Clapp (1914), with emphasis on location and description of coal seams. Later, Usher (1952) described the Cretaceous ammonite faunas and Bell (1957) described the Cretaceous flora of the Vancouver Island coal dumps. More recently, Muller and Carson (1968) and Muller and Jeletzky (1970) described the geology, biochronology and stratigraphy of the Late Cretaceous Nanaimo Group of Vancouver Island and the Gulf Islands, B.C. Their mapping was at a scale of 1:250,000.

Geography

The topography of the Duke Point-Kulleet Bay area is mostly controlled by the underlying strata. The De Courcy Formation sandstones are gently folded into a series of anticlines and synclines plunging 8-12° and with dips on the fold limbs ranging 5-25°. The fold limbs have been truncated by erosion, principally and most recently by glacial scour, and differential erosion has produced many strike ridges and valleys. The extensive homocline of the Woodley

Range, which trends N. 40° E., have been faulted, truncated by erosion and glacially scoured, and forms a topography of parallel valleys and ridges that trend northwest. The ridges are asymmetrical and covered with moss, thick brush, and arbutus and evergreen trees. The valleys are for the most part poorly drained and locally they are filled with tall grass, reeds, ferns and stagnant water. The overall effect is one of alternating ridges and swamps. The ridges rise from 20 to 150 feet above the valley floor and are 500 feet to one-half mile from ridge crest to ridge crest (see cross-section, Plate II).

The older mudstones of the Cedar District Formation form extensive, featureless, cultivated lowlands. Most of the drainage flows seaward across these less resistant strata.

The configuration of the coastline is mainly controlled by well-exposed, though deeply weathered, sandstones of the De Courcy Formation (Plate I). However, the Cedar District mudstones form flat, wave-cut platforms, covered by organic debris, talus, and glacial drift along a two-mile interval starting one mile southeast of Joan Point, and terminating three-fourths of a mile north of Reynolds Point (Figure 1). This part of the coastline is relatively straight in contrast to the highly indented sandstone shoreline. The mudstone interbeds in the thick sandstone units form narrow inlets and pocket beaches of sand- and shell-covered mudstone that parallel the strike of the strata.

Overall, the shore is littered with talus from the De Courcy sandstones, logs, seaweed and glacial drift that includes sandstone, limestone, conglomerate and igneous rocks ranging from granodiorite to gabbro. Glacial erratics generally increase in size north from Yellow Point to Joan Point, ranging from pebbles to small boulders near Yellow Point to pebbles and immense boulders (up to 10 feet in diameter) near Joan Point.

The maximum relief of the Duke Point-Kulleet Bay area is 700 feet, from sea level to the crest of the Woodley Range, which parallels and forms the northeast shore of Ladysmith Harbor.

The climate is West Coast marine (Koppen, 1931), with a minimum temperature of approximately 10° F in January and a maximum temperature of approximately 100° F in July. The summers are relatively dry and the winters wet with an average annual rainfall of 60-65 inches (Kendrew and Kerr, 1955).

Table 1. Summary of stratigraphic units, Duke Point-Kulleet Bay area, Vancouver Island, B. C.

Age		Rock-stratigraphic unit and thickness	Lithology
Late Cretaceous	Late Campanian	De Courcy Formation (1400 feet thick)	Light- to medium-gray sandstones exhibiting cross bedding, laminae, channeling, scour-and-fill structures and carbonaceous concretions; minor pebble conglomerate and medium-gray intercalated mudstones. Principally ridge-formers.
		Conformable	
Late Cretaceous	Late Campanian	Cedar District Formation (992+ feet)	Medium- to dark-gray mudstones; fine- to medium-grained intercalated sandstones exhibiting laminae, grading and cross-bedding; sandstone dikes; limy concretions; minor micrite lenses.
		Base not exposed	

STRATIGRAPHY

Cedar District Formation

Name

The name Cedar District was chosen by Clapp and Cooke (1917) for the marine mudstones overlying the Nanaimo Basin coal measures. Cedar, a geographical division (district) similar to the counties of the United States, is the location of this formation type section.

Basal Contact

The basal contact between the Cedar District and the underlying Extension-Protection Formation lies below tide level on the coast of the thesis area and is not exposed. Muller and Jeletzky (1970) note that the basal contact is well defined in other locations within the Gulf Islands, where usually a thick mudstone unit overlies sandstones with intercalated mudstone beds. On Saturna Island the transitional near-shore sandstone facies overlies conglomerate of the Extension-Protection Formation.

Distribution and Thickness

A section 992 feet thick was measured and described on the coast south of Dodd Narrows (Figure 4; Appendix I; and geologic map,

Plate I), beginning at the axis of the Trincomali Anticline and traversing part of the southwest limb. An error in measurement of at least 10% should be allowed for instrument imperfection, subtle changes in strike and dip and human fallacy. The exact base of the formation is not exposed, even at low tide, but presumably lies somewhere near the coast.

Cedar District mudstones along the coast are overlain by the De Courcy Formation sandstones; the latter locally protect the mudstones from weathering and erosion. Wave erosion is dominant and has eroded the coast at a fairly uniform rate, resulting in a relatively straight shoreline. Inland exposures are rare and are limited to thin, alternating mudstone and sandstone beds that are exposed in roadcuts or excavations for houses and water wells.

Lithology

The rocks of the measured and described section of the Cedar District Formation are mostly medium dark gray (N4), slightly silty, laminated mudstones that weather in discoidal chunks one-half to two inches in diameter. Micrite lenses one-half to five inches thick and up to 20 feet wide are scattered throughout the unit, but the lenses are more prominent within the upper and lower 200 feet. Limy mudstone concretions up to six inches in diameter occur near the micrite lenses. The concretions are widely scattered, but worthy of note because a fossil mold of what appears to be part of an ammonite shell was found in one of them (Figure 2).

Numerous sandstone dikes or sills appear throughout the upper 450 feet of the formation; these were observed to range in thickness from one-half inch to seven feet and in length from about 15 feet for the smallest to hundreds of feet for the larger ones. Some of the larger dikes stand out as resistant ribs on the coast. The seven-foot-thick dike is located on the coast one mile south of Brightman Road (Plate I) and has a boat ramp built upon it. The thickness of a single dike body may vary as much as 18 inches within an interval of 15 feet. None of them could be traced to their source, but presumably they were beds or lenses of sand subjected to spontaneous liquefaction prior to cementation, and injected along faults or joints into the overlying cohesive muds. Minor faults (offset two inches to five feet) and intraformational slump structures reflect some tectonic instability. Most of the dikes appear to follow these partings, and in many instances do not greatly disrupt the bedding. However, some of the dikes and sills are offset by other small faults (approximately the same magnitude as before) indicating movement after induration. No sandstone dikes were found in the lower 550 feet of the section.

The sequence exposed on the northeast limb of the Trincomali Anticline is very different from the one just described. Very few sandstone dikes and sills or concretions appear, the beach is littered

Figure 2. Fossil mold found within a limy concretion of the Cedar District Formation.

with cobbles and boulders of granitic rocks and sandstones, and the mudstone is stained a moderate reddish orange (10 R 6/6) from the weathered products of the overlying De Courcy Formation sandstone beds. Most notable is the variation in contact with De Courcy Formation. The measured and described section of the Cedar District Formation of this paper (Appendix II) has a very sharp, gently undulating, conformable contact with thick sandstone beds overlying thick mudstone units (Figure 3). On the other hand, the contact with the De Courcy Formation on the northeast anticlinal limb is gradational (see De Courcy Formation, Basal Contact section, and Appendix III) but still identifiable. Fine- to medium-grained sandstone beds one-fourth to four inches thick appear 800 feet from the base of the formation, separated by mudstone layers five to 20 feet thick. The sandstones become thicker and more closely spaced upward. Some of the sandstone beds show normal grading, parallel laminae and asymmetrical current ripple marks that may record density currents generated from a delta front or basin margin. The possibility exists that the sandstone dikes so prevalent on the southwest flank of the anticline may have been derived from beds similar to these, but no supporting evidence has been found. These thin beds do not appear to contain enough material to supply sandstone dikes three to seven feet thick.

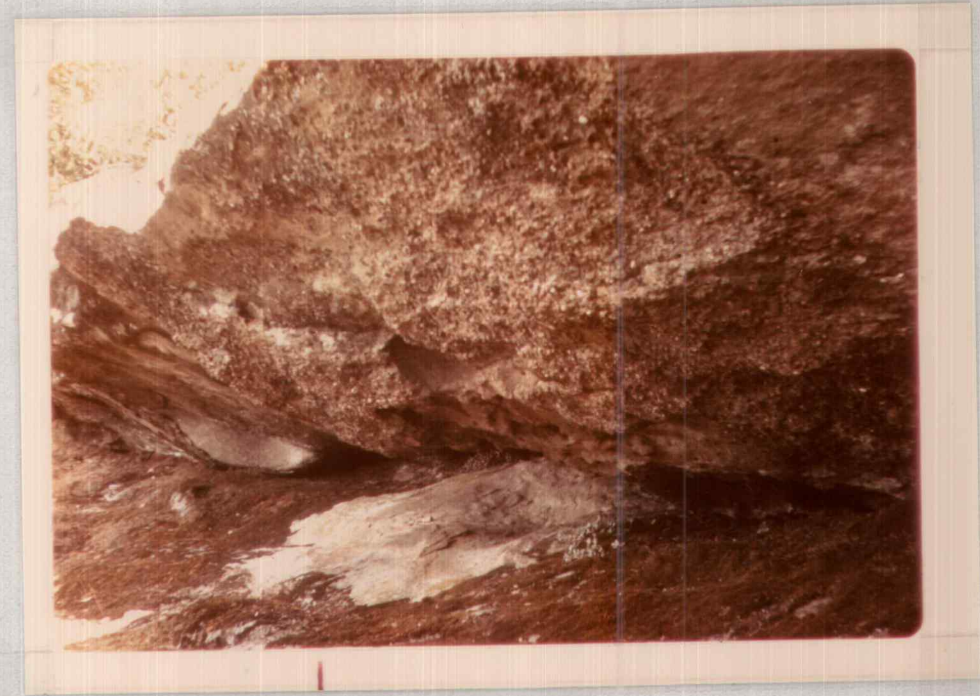


Figure 3. De Courcy-Cedar District Formational contact at the top of the Cedar District measured and described section.

Depositional Environment and
Source Areas

The lateral variations within the formation are interpreted to represent facies changes. The area containing the gradational contact represents a gradual change from offshore marine to fluvial-littoral environment. Usher (1952) described the Late Cretaceous ammonite faunas of the Cedar District Formation found in the Nanaimo Basin. Although no fossils have been found or described within the thesis area, Usher (1952) and Muller and Carson (1969) have concluded that the Cedar District mudstones, described above, represent an offshore marine environment whose floor was below wave base. The intervals containing intercalated sandstone beds probably represent a similar environment close enough to a shoreline to allow intermittent invasion of coarser-grained sediments delivered by infrequent shocks due to storm waves or earthquakes. The transition from sediments dominantly clay-size to sediments dominantly sand-size is interpreted to represent a shallow marine and/or littoral environment.

The sharp contact between the Cedar District and De Courcy Formations in the measured and described section represents an abrupt change in depositional environment or sediment load and will be discussed under the heading of De Courcy Formation, Depositional Environments and Source Areas.

The provenance of the Cedar District Formation sediments lay to the south and southwest. The sediments were derived from Early- to pre-Cretaceous intrusive, volcanic, and metamorphic rocks (Muller and Jeletzky, 1970; Symons, 1971).

De Courcy Formation

Name

The name De Courcy was introduced by Clapp (1912a) after the De Courcy Islands which are underlain by this resistant formation of sandstone and conglomerate.

Basal Contact

The De Courcy Formation overlies the Cedar District Formation, and the contact in character is variable within the thesis area. The contact at the top of the writer's measured and described section of the Cedar District Formation on the coast south of Dodd Narrows (see Appendix I for exact location) is remarkably sharp and gently undulatory, with a 20-foot sandstone bed overlying approximately 1000 feet of mudstone. Conversely, the basal contact one mile south of Joan Point is gradational over a 120-foot interval with a high mudstone/sandstone ratio (7:1) at the bottom of the interval changing to a high sandstone/mudstone ratio (8:1) at the top. The sandstone-over-mudstone contacts are well but not sharply defined. The Cedar District-De Courcy formational contact at the base of measured and described section 3 (Figure 4) was arbitrarily placed at the base of the thickest sandstone bed (two feet thick) near the center of the 120-foot interval (Figure 4 and Plate I, I. P. 3). The basal contact at the foot of the Woodley Range, northeast of Ladysmith Harbor, was arbitrarily chosen at the sharp break in slope above the cultivated fields. The De Courcy-Cedar District Formational contact along the eastern shore of Quennell Lake is disturbed by faulting and is covered with vegetation.

Distribution and Thickness

The writer measured and described two sections in the De Courcy Formation: a presumably complete section in the Woodley Range--1355 feet in thickness--which is mostly covered, and a partial section--encompassing the basal 447 feet--terminating at Joan Point (see Appendices I and III for exact initial and terminal points). The errors in measurement noted in Cedar District Formation, Distribution and Thickness should again be taken into account. The incomplete section traverses the northeast limb of the Trincomali Anticline and was chosen for its completeness of exposure and its lack of structural complication by the faults that are so characteristic of the southwest limb.

The De Courcy Formation is exposed on the coast from Duke Point to Kulleet Bay; the only break in continuity of exposure is a

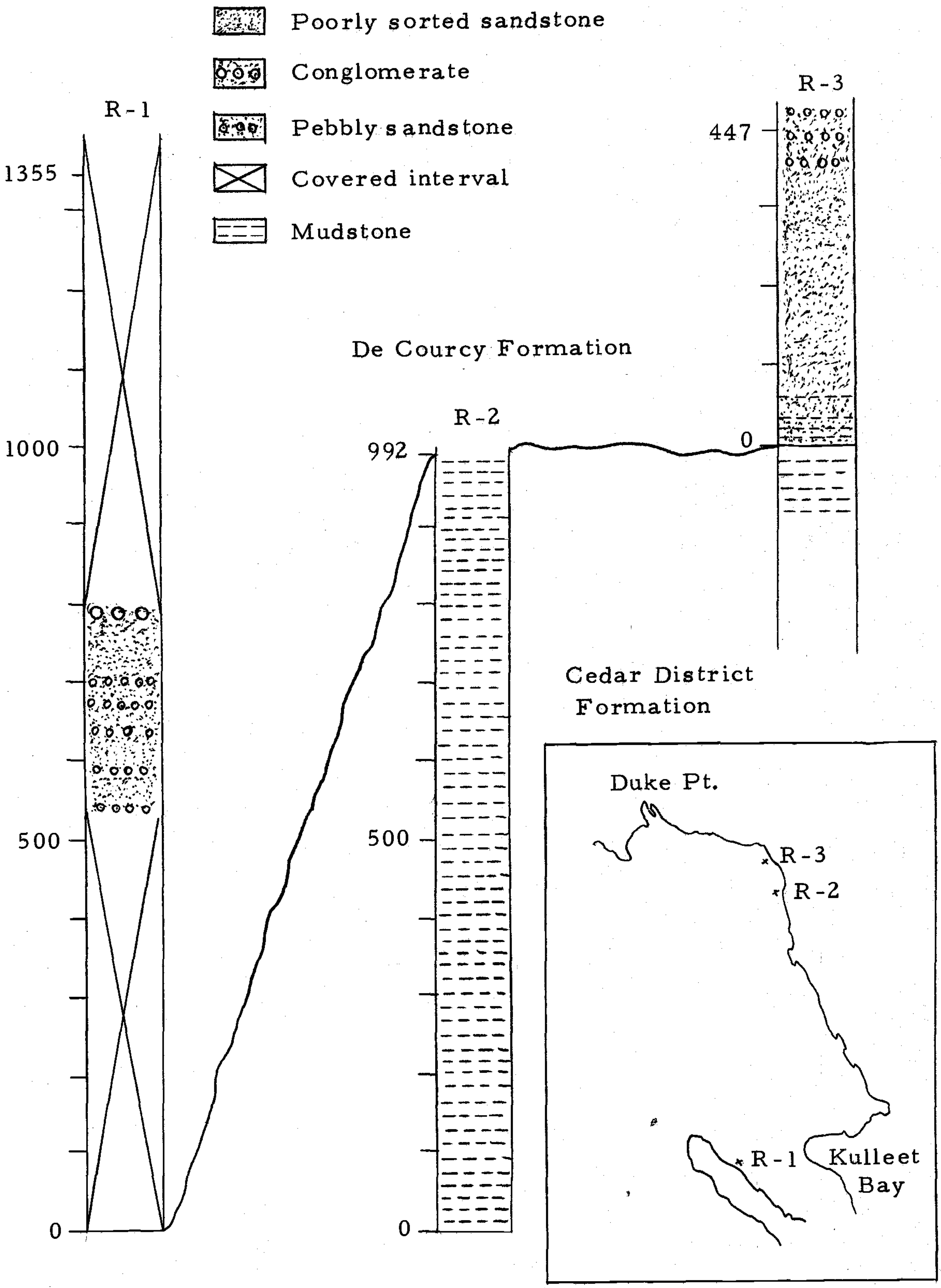


Figure 4. Thickness, lithology and location of the measured and described sections of the De Courcy and Cedar District Formations (see appendices I, II, and III).

two-mile stretch of Cedar District mudstones between points 0.6 mile north and 1.4 miles south of Brightman Road's dead-end, which lies 0.4 mile S. 70° W. from Round Island.

Lithology

The rocks of the De Courcy Formation represent a marine transgression during the Late Cretaceous (Muller and Jeletzky, 1970). The lower beds resemble the turbidite (?) sequences in the upper Cedar District Formation, but within 120 feet, stratigraphically, the beds exhibit characteristics of fluvial-deltaic sedimentation types. Channels up to 25 feet deep and 50 feet wide were found throughout the formation, with a variety of sedimentary structures within them. Some of the channels are characterized by thinly-laminated sets of strata two to five inches thick at the channel axis, pinching out three to 25 feet toward the lateral margins. More commonly, the channels are thin- to thick-bedded and exhibit multiple scour-and-fill structures and festoon cross-bedding. Planar, laminated foresets, inclined 15 to 30° to the bedding plane, and in sets up to 30 feet in thickness, were observed nearly everywhere along the coast and at several locations inland. The foresets are excellent indicators of paleocurrent directions and with the festoon bedding, also common throughout the formation, provided most of the paleoslope data (see Paleocurrent Data). Storm waves have cut galleries in some of the coastal sandstones, and the fresh surfaces, protected from chemical weathering, exhibit the best sedimentary structures. Laminae and cross-laminae stand out in relief and are of value in determining paleocurrents.

The incomplete measured and described coastal section is, in the gross sense reverse graded, from a thinly-laminated, fine-grained, silty sandstone at the base, to a coarse-grained featureless sandstone at the 300-foot level and finally to a medium- to coarse-pebble sandstone at the 450-foot level. The increase in grain size of a unit is commonly signalled by the appearance of lenses of coarser material in the finer underlying beds; these channel fills become more prominent over a vertical interval of 75 to 100 feet until the coarser material becomes dominant.

The measured and described section in the Woodley Range (Appendix I), though mostly covered, appears to continue the trend of increasing coarseness upward. Lenses of pebble to cobble conglomerate at the 500 to 600 foot level change to predominantly conglomerate units at the 700 foot level. The 700 to 1400 interval traverses dip slopes, and cannot be identified as a massive conglomerate unit as the trend of progressive increase in grain size upward may indicate. Clapp (1914a), Usher (1952), and Muller and Jeletzky (1970) report that elsewhere in the Nanaimo Basin the De Courcy Formation grades upward into the Northumberland Formation "shales," so one can only speculate about trends in a discrete area.

Though not specifically mentioned in the texts, Muller and Carson (1969) and Muller and Jeletzky (1970) indicate on their geologic maps that the Kulleet Bay Syncline (bounded by Deer Point, Michael Lake and the Woodley Range) is part of the mudstone-dominant Northumberland Formation. However, the entire shoreline of Kulleet Bay is composed of sandstones, not unlike those along the rest of the coast. Subtle differences do occur, but not of such magnitude to justify differentiating the sandstones into two separate formations.

Carbonate concretions ranging from four inches to five feet in diameter are scattered throughout the De Courcy Formation. They range from spheroidal to ellipsoidal in shape and commonly stand out in relief because of a higher resistance to weathering and erosion than the enclosing sandstone strata. Many of them have deeply weathered horizontal to vertical joints which do not extend into the surrounding units, nor can these always be correlated with nearby joint systems. Only one fossil was found within the concretions (more undoubtedly exist), but it was unrecognizable due to recrystallization. A halo of crystalline calcite surrounds it indicating an elongate, tapering shelled animal rather than a burrow or floral debris (Figure 5). In places, belts of concretions can be traced along bedding planes for hundreds of feet without deviating, whereas others are scattered in random locations with varying orientations. The concretions from Deer Point north-northwest to Jack Point weather to a pale yellowish brown

Figure 5. Fossil from sandstone concretion of the De Courcy Formation.

(10 YR 6/2). Fresh surfaces are light olive gray (5 Y 6/1). From Deer Point along the coastline of Kulleet Bay the concretions are iron-stained by hematite and limonite to a grayish red (5 R 4/2) and a light olive gray (5 Y 5/2). Fresh surfaces are medium light gray (N 6).

North of Yellow Point the sandstones within the littoral zone weather to irregularly patterned honeycombs and caverns which are partly attributed to the weathering out of concretions. The pits range from one inch to seven feet across, but are not continuous along the coast. Southwest of Yellow Point and into Kulleet Bay the honeycombing becomes more regular. Only small pits are found, averaging one and one-half to two inches across. The concretions in this area are less resistant than those farther north, weathering at nearly the same rate as the parent sandstones. Muller and Jeletzky (1970) state that the honeycombs result from differential weathering. Carbonate-filled fractures stand out in relief from the less resistant sandstones, forming solution pits.

Depositional Environments and Source Areas

A variety of depositional environments can be recognized within the De Courcy Formation. The lower beds represent a transition from the offshore marine Cedar District Formation mudstones to the nearshore marine De Courcy Formation sandstones. The transitional sandstone beds were deposited below wave base by density and/or tractive currents originating at a nearshore provenance. Some of these beds are normal graded very fine- to medium-grained sand with parallel laminae of fine sand above and below the graded interval. Other beds lack the grading and are homogeneous and featureless. Shepard, Dill and Von Rad (1969) demonstrated that sand beds in pelagic muds could be derived by tractive or density currents with essentially the same sedimentary structures resulting. For lack of more positive evidence, the discussion will not be carried further.

Above the transitional beds lie thicker (two to 15 feet) units of poorly sorted coarse- to fine-grained sandstones, with thinner (three inches to one and one-half feet) intercalated mudstones. If the mudstone exposures were parallel to the paleoslope rather than perpendicular to it, these beds could probably be traced and shown to intertongue with the thinner offshore beds. The thicker sandstone beds contain slump structures, flute casts, symmetrical and asymmetrical ripples, sand waves, laminations, festoon bedding, channel cross-beds and multiple scour-and-fill structures. Foreset beds are of two kinds: thin cross-beds probably resulting from migrating ripples and dunes, and very thick cross-beds, up to 30 feet thick, such as one may find on a foredelta. The ripples have wave-lengths of one to five inches and amplitudes of 0.1 to 0.8 inch. The very thin intercalated mudstone to very fine sandstone beds show many of the same structures as the thicker beds, but on a much smaller scale, and represent periods of relative quiescence in low energy, unidirectional current deposition (Figure 6). All the above structures were helpful in obtaining paleoslope directions.

Higher in the section channels of pebbly sandstone appear, representing higher energy stream deposition closer to the source rocks. The channels become larger up section, finally becoming continuous pebbly sandstone beds. Conglomerate lenses grade into beds of indeterminate extent in the Woodley Range, indicating a high energy environment of fluvial channel deposition and/or erosion of a nearshore headland and reworking by wave action.

Past authors have referred to the De Courcy Formation as a continental-to-littoral deltaic sequence, but the exposures in this area are not sufficient to allow me to use the term "delta" with any force. The formation extends for 90 miles northwest to southeast, but only 12 of those miles have been taken into account here. The sedimentary structures in this area can be found on deltas, floodplains and in littoral environments. If the area is indeed deltaic, and it well might be, comparison has yet to be made to modern deltas; therefore, it is difficult to describe it in such a manner as to give a concise picture of what it looked like during the time of formation.

The source area(s) for the De Courcy and Cedar District formations lay to the south and southwest (Figure 12). Source rocks include

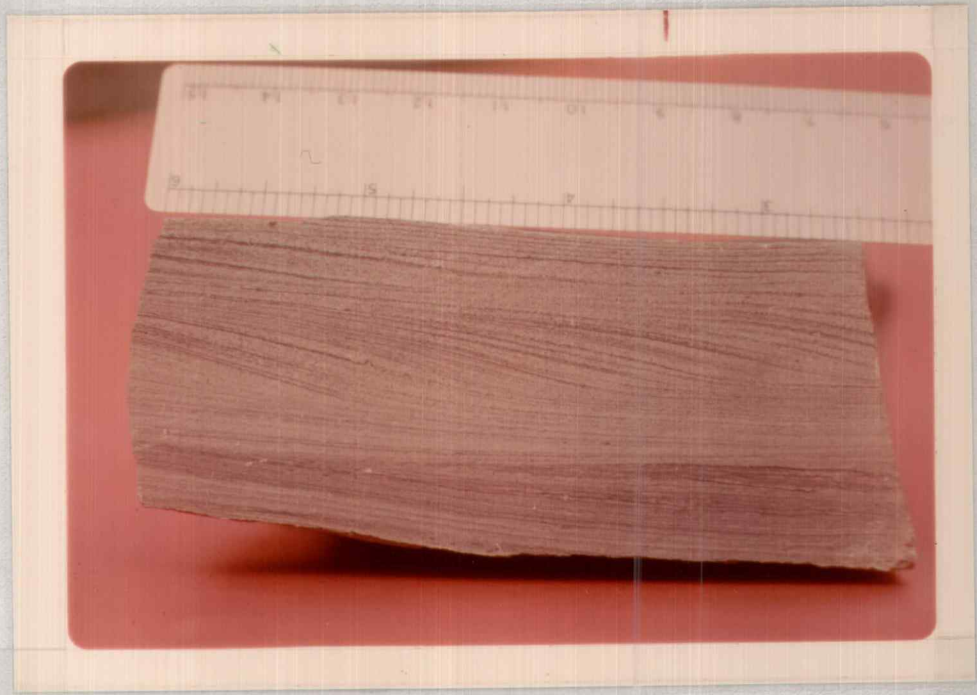


Figure 6. Very fine-grained sandstone showing parallel laminae and thin cross-beds. Current direction left to right.

Early to pre-Cretaceous intrusive, volcanic and metamorphic rocks occupying what is now the approximate long axis of Vancouver Island (Muller and Jeletzky, 1970).

PETROGRAPHY OF THE SANDSTONES

Locations of sandstone samples are indicated on Figure 7. Seventeen thin-sections of these sandstones were examined petrographically, and a modal analysis conducted on each to determine percentages of constituents. The rocks were named using Gilbert's (1954) classification of sandstones.

Quartz

The most abundant detrital mineral is silica. Occurring mainly as quartz, with subordinate chert and quartzite, it forms 40.5% of the total rock composition. Individual grains of quartz are clear, but sericite occurs as a replacement mineral to a minor degree. Grains range from well-rounded pebbles to angular, very-fine sand grains; the average grain size is medium sand. All but the pebbles are angular to sub-angular indicating little, if any, reworking and relatively short distances of transport. Sorting is poor in all except the fine-grained beds of sandstone intercalated in mudstone units, which are seldom more than two inches thick. In one sample the quartz grains are intergrown on their peripheries with "ghosts" showing former boundaries. This occurrence is attributed to pressure solution.

Chert and quartzite comprise less than 3% of the total composition of the rocks studied, and occur as pebbles as well as fine-grained detritus.

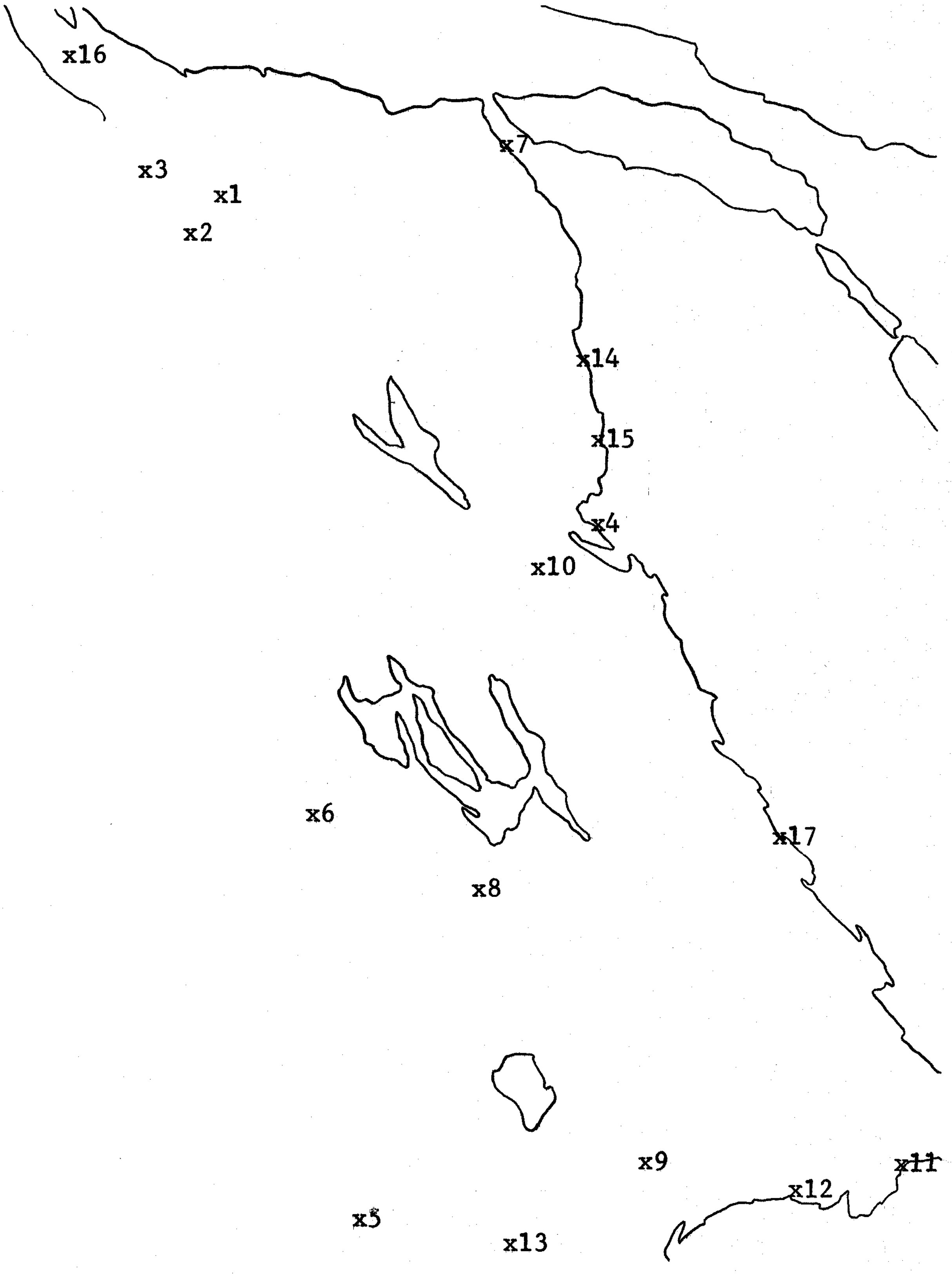


Figure 7. Location of sandstone samples.

Sources for the silica grains are variable, and are discussed in the Geologic History section. Clear quartz was probably derived from the Island Intrusions and from recycled sandstones and conglomerates of older formations in the Nanaimo Group. The chert and quartzite grains were likely derived from the bedded cherts and metamorphic rocks of the pre-Pennsylvanian to Permian Sicker Group.

Feldspars

The feldspars, next to quartz in abundance, total 27.6% of the rocks, with potassium and plagioclase feldspars 19.2 and 8.4% respectively. Grains range from coarse- to very fine-sand, the average being medium sand. There is little rounding except of pebbles in the pebbly sandstones. Most grains are angular to subangular and the rocks are very poorly sorted.

The feldspars show varying degrees of weathering and alteration with kaolin, calcite and sericite as products. One slide reveals a halo of hematite around every feldspar grain, in some instances penetrating twinning planes and fractures indicating post-depositional formation. Calcite is common as both a cement and an alteration product, and is observed to have wedged apart grains of plagioclase during secondary growth along fractures.

The most common potassium feldspars are orthoclase and sanidine; only rarely is microcline present. Labradorite (An_{53}-An_{62})

is the only plagioclase feldspar positively identified. The orthoclase and microcline were probably derived from the Jurassic Island Intrusions; the sanidine may have been derived from the pre-Cretaceous volcanic rocks of Vancouver Island; the labradorite grains could be both igneous and metamorphic in origin, so the sources postulated are the Island Intrusions and the Sicker Group metamorphics.

Micas

The micas biotite, muscovite and sericite make up 14% of the total rock composition. Biotite occurs in microscopic fragments and as elongate plates up to five millimeters in length; it makes up 11.6% of the total rock composition. Muscovite occurs as microscopic fragments less than one millimeter in length and forms 1.4% of the total rock composition. Sericite clouds feldspars and occurs as microscopic grains composing less than 1% of the total rock composition.

Biotite is the only mica exhibiting weathering and alteration, with the most common products being magnetite and hematite. Muscovite is stable and shows no alteration whatever. Sericite results from alteration of quartz and plagioclase feldspar.

Magnetite and Hematite

Magnetite and hematite occur in trace amounts totaling less than 1% of the rock composition. Magnetite occurs both as a detrital mineral and as an alteration product of biotite and chlorite. Hematite occurs as an alteration product of magnetite and some argillaceous matrix materials.

Volcanics

Basaltic rock fragments occur throughout the rock samples, occurring in 16 out of the 17 studied, in quantities ranging from less than 1% to 19% of individual rocks. Sizes range from large pebbles to medium-sand size.

Illite

Illite occurs in all rock specimens, ranging from less than 1% to 12% of the individual samples. It occurs as medium-pebble size grains of altered feldspar and argillaceous matrix and cement. Sources are rocks of the early Late Cretaceous Nanaimo Group, the Karmutsen Formation and the Sicker Group.

Calcite

Calcite occurs as cement in six of the thin-sections examined and as a minor replacement mineral of feldspar in samples 9 and 11. Quantities range from less than 1% to 18% in individual samples and always as a secondary mineral.

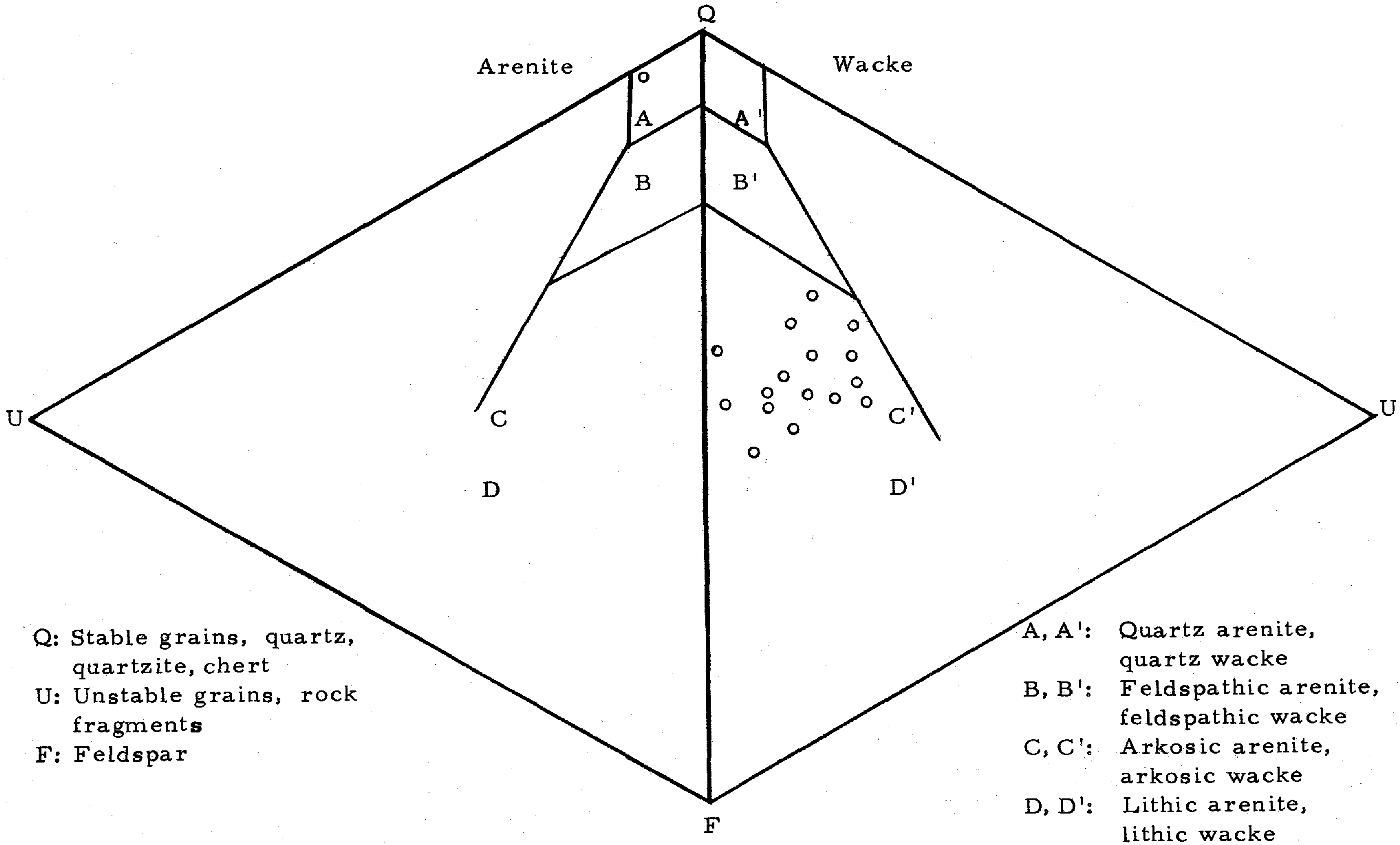
Trace Minerals

Sphene, rutile, chlorite, epidote, and zeolites occur as trace minerals amounting to less than 1% of the total rock composition. Sphene occurs in all slides in grains of fine- to very fine-sand size. Rutile occurs in only five of the slides as microscopic laths. Chlorite occurs as an alteration product of biotite in quantities and sizes so small as to be nearly unrecognizable. Sphene and rutile were probably derived from the Island Intrusions. Epidote was derived from the Sicker Group metamorphic rocks and possibly as an alteration product of plagioclase feldspar. Two slides contain zeolites as void fillers (Figure 8).

Rock Types

All but one of the rocks are classified as arkosic wackes (Gilbert, 1954) (Figure 9). The one exception is classified as a quartz arenite; it represents a fine-grained sandstone from within a gradational sequence of mudstones and sandstones, averaging less than three inches in thickness, between the De Courcy and Cedar District Formations.

Figure 8. Zeolite as a void filler in an arkosic wacke. Bounded by biotite, muscovite, quartz and feldspar.



Q: Stable grains, quartz, quartzite, chert
U: Unstable grains, rock fragments
F: Feldspar

A, A': Quartz arenite, quartz wacke
B, B': Feldspathic arenite, feldspathic wacke
C, C': Arkosic arenite, arkosic wacke
D, D': Lithic arenite, lithic wacke

Figure 9. Classification of sandstones (using method of Gilbert, 1954).

STRUCTURE

General

The Duke Point-Kulleet Bay area has been tectonically active, but is not structurally complex. Faults, folds and the stratigraphy control the larger topographic features such as lakes, bays, points, ridges, valleys and the principal drainage. Joints partially control smaller local features, such as abbreviated pocket beaches and very narrow inlets, by exposing a greater surface area to weathering and erosion.

Faults

The main fault system trends roughly N. 40° W. and consists of steeply dipping normal faults, southwest block down relative to the northeast block, anastomosing or branching out into zones up to one mile in width. Cross faults strike 60 to 90° to the main system (see map, Plate I). Some of the anticlines and synclines have faults paralleling their axes, suggesting an application of stress to rocks behaving in a brittle manner. The syncline between the Trincomali Anticline and Yellow Point has a faulted axis trending N. 35° W. Holden and Greenway Lakes are situated along a line approximating the fault. The Yellow Point anticline is cut by a fault striking 7° to it (se map, Plate I). A fault could be inferred to follow the trend of the western half of the Trincomali Anticline, but outcrop evidence of faulting is scanty (two faulted outcrops 1.75 miles apart). Therefore, the geologic map (Plate I) shows two non-connected faults, one at the northwestern-most arm of Holden Lake and the other 0.4 miles west of the town of Cedar. Previous authors have shown the Kulleet Bay Syncline to be faulted (Muller and Carson, 1969; Muller and Jeletzky, 1970), but no positive field evidence for such a feature was found.

In a number of places the faults provide structural basins for entrapping water as lakes and marshes. Greenway and Holden Lakes have already been mentioned. Quennell Lake is a sprawling feature (see map, Plate I) consisting of four N. 30° W. trending arms, connected by two N. 55° E. trending depressions. The entire feature is fault-controlled. Michael Lake is located in a depression formed by the branching of a large fault through the Woodley Range. Long Lake and the marshes to its northwest and southeast are aligned along a fault that can be traced from Quennell Lake to Yellow Point.

Two major coastal features are the result of faulting. Ladysmith Harbor has formed partly by erosion along a N. 35° W. trending fault. The Nanaimo River mudflats were formed by one or more north-northwest trending faults in the Cedar District Formation mudstones (see map, Plate I).

Another major fault bisects the Woodley Range northeast of Ladysmith Harbor. The fault trends N. 20° E. from Page Point in the harbor, passes through Michael Lake, and branches into two faults, one trending N. 10° E. and the other trending N. 35° W. The Woodley range cuesta is offset 200 feet vertically, southeast block down (see map, Plate I).

Sutherland-Brown (1966) considers the Late Cretaceous to Tertiary structure of the Nanaimo Basin to be tilted fault blocks that are the surface expressions of basement fault movements.

Folds

Like the faults, the folds of the Duke Point-Kulleet Bay are part of an overall northwest to southeast alignment in the northern Gulf Islands. On a geologic/topographic map the overall expression of islands, lakes, harbors, bays, faults and folds follows this trend.

There are two major folds and many minor ones within the thesis area. The Trincomali Anticline is one of the largest folds; its axis plunges 16° S. 35° W. at the base of the Cedar District Formation measured and described section (see Appendix I, and map, Plate I for location). The axis hooks 100° northwest, finally trending N. 45° W. through the Nanaimo River mudflats. The flanks of the anticline are composed of De Courcy sandstone dipping 10° to 40°, and locally, particularly south of the Harmac pulp mill, form a series of imbricate cuestas. The fold has been disrupted by faulting, exposing the less resistant Cedar District mudstones to erosion; these underlie an anticlinal valley starting two miles inland from the Stuart Channel and continuing northwest through the Nanaimo River mudflats. A number of smaller folds have been formed within the Trincomali Anticline. Some of these folds are local undulations of the flanks and one, between the Harmac pulp mill and the Dodd Narrows, formed as a result of the bending of the fold axis of the anticline, possibly representing a later episode of deformation.

The other major fold is the Kulleet Bay Syncline, mentioned in the section on faults, plunging 9° S. 50° E. into Kulleet Bay. The fold can be traced northwest approximately one mile, then is lost in the Woodley Range homocline (see Plate II, structural cross-section A-A'). The rocks are all De Courcy sandstones, dipping 9 to 15°; they are very monotonous in character around the bay. The southwest limb terminates at the crest of the Woodley Range cuesta where it was truncated by the fault running through Ladysmith Harbor. The northeast limb rolls over at Yellow Point, forming a small anticline plunging 8° S. 50° E. Other small folds can be found between Yellow Point and the Trincomali Anticline, but in most cases they can be traced only two miles or less.

Regionally the thesis area can be viewed as a large, northwest-plunging anticline, the Trincomali, that lies adjacent to a large southeast-plunging syncline, the Kulleet Bay. Smaller flank folds between them are the reflection of the large scale "twist" necessary to rotate the major fold axes approximately 20° from each other in a vertical plane.

Joints

Joint systems on the whole trend approximately N. 40° W. with lesser systems very prominent and trending in every compass direction. Joints are not as dominant as faults and folds in influencing surficial features of this area. The outcrops on the coast show the effects of jointing more readily than do inland exposures. Pocket beaches and small inlets form in areas where the joints are deeply weathered. Some parts of the coast are so badly broken that they resemble crushed fault zones, but they lack the offset and slickensides necessary to call them faults. "Joint zone" might be a better term.

PALEOCURRENT DATA

One hundred and ninety-nine directional measurements were recorded in determining the paleoslope and source areas for the De Courcy and Cedar District Formations (Figure 10). Measurements were placed into four categories: 1) Readings from Brightman Road north to Duke Point with a mean paleoslope descent bearing N. 63° E., 2) readings from Brightman Road south to 49° 04' latitude through the southernmost arms of Quennell Lake with a mean paleoslope bearing N. 55° E., 3) readings from 49° 04' latitude south to Kulleet Bay and Ladysmith Harbor with a mean paleoslope bearing N. 50° E., and 4) readings from 1, 2, and 3 above with a mean paleoslope bearing N. 60° E.

Structures used in measuring paleoslopes include asymmetrical ripple marks, flute casts, intraformational slump structures, sand waves, festoon bedding and foreset beds. In a few instances, symmetrical or erosion truncated ripples and channel axes perpendicular to the outcrop surface yielded bidirectional readings and one measurement was logged for each direction (Figure 11). If a variety of structures within an outcrop yielded the same slope direction, only one measurement was recorded.

Most measurements were made on the coast where channel axes and foreset strata were etched by erosion and weathering.

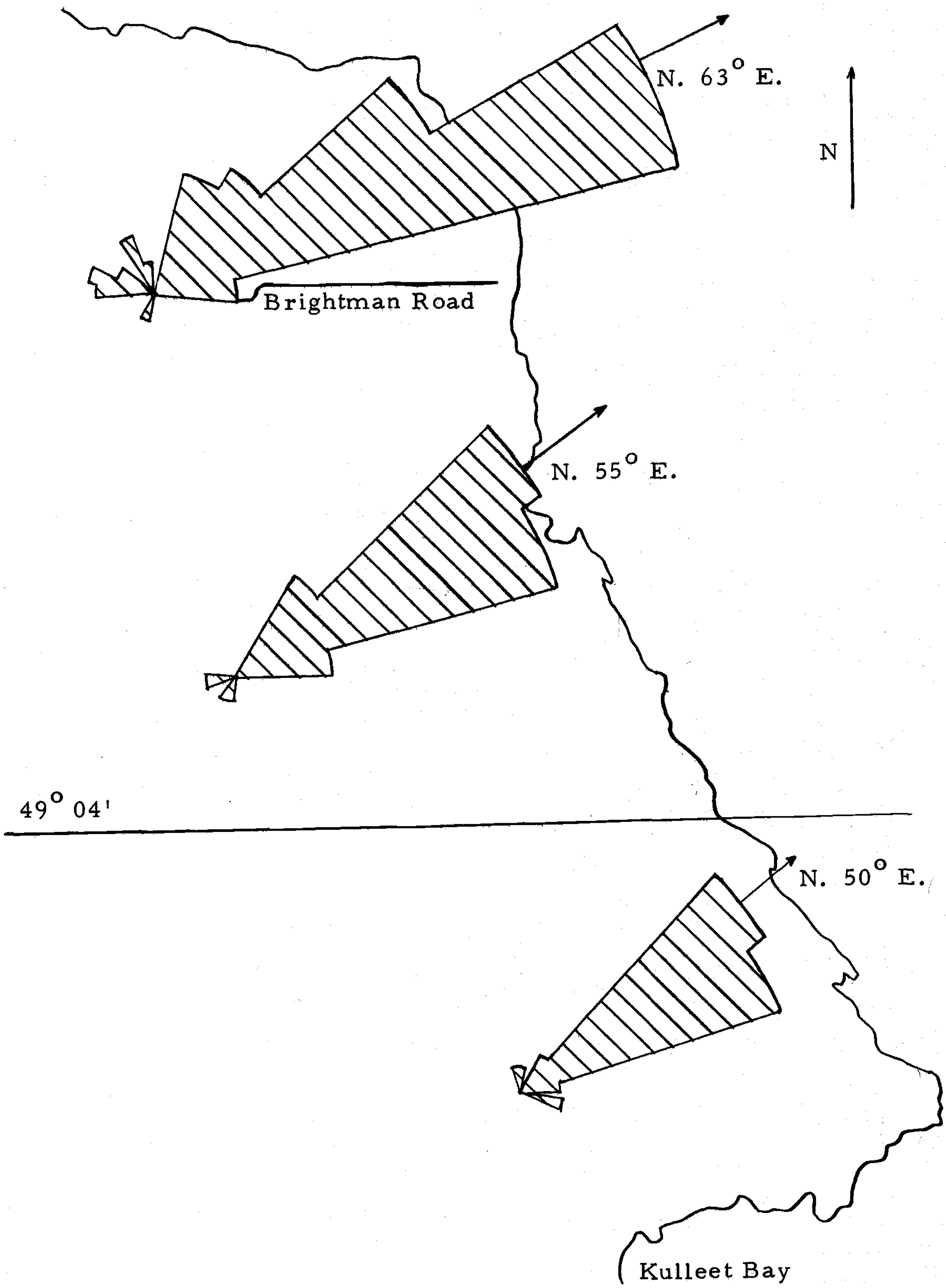


Figure 10. Paleocurrent data using 15° intervals. Every 0.1 inch represents one reading. Mean paleoslope for all data is N. 60° E.

Figure 11. Oscillatory ripple indicating bidirectional current.

Measurements taken inland were recorded from recent roadcuts, glacially scoured dip slopes yielding sand waves and ripples, and from bedrock exposed in fault scarps.

GEOLOGIC HISTORY

The oldest rock sequence in the Nanaimo Basin is the Sicker Group of pre-Pennsylvanian to Early Permian age, composed of 10, 000 feet of volcanic and pyroclastic rocks, 2000 feet of argillites, greywackes, conglomerates and minor limestones, and up to 1000 feet of limestone and bedded chert (Muller and Carson, 1969).

Unconformably overlying the Sicker Group is the Vancouver Group of Early Permian to Early Jurassic age, which comprises the Karmutsen Formation, the Quatsino Formation and the Bonanza Subgroup. The Karmutsen Formation of Early Permian to Late Triassic age includes pillow-basalt and pillow-breccea, basaltic lava, and minor tuff. The thickness of the Karmutsen volcanics ranges from 7000 to 19, 000 feet, not including the comagmatic dikes and sills, which range up to 500 feet in thickness. The Quatsino Formation of Late Triassic age is composed of limestones 500 to 2000 feet in thickness. The Bonanza Subgroup of Late Triassic to Early Jurassic age consists of two parts, sedimentary and volcanic. The sedimentary part, consisting of 500 to 1500 feet of limestone and argillite, is overlain by 1000 feet of andesitic to dacitic breccias, tuffs and lavas with minor argillite and siltstone (Muller and Carson, 1969).

During Middle to Late Jurassic time the Sicker and Vancouver Groups were cut and deformed by the Island Intrusion composed of biotite-hornblende granodiorite, quartz diorite and gabbro (Jeffery and Sutherland-Brown, 1964).

The ages, distribution and results of the petrographic analysis of the above rock sequences indicate that they were the primary source rocks, bounding the Nanaimo Basin on the south and southwest and issuing sediments for the Late Cretaceous Nanaimo Group rocks (Figure 12).

The Nanaimo Group consists of nine formations representing four two-stage depositional cycles and a fifth incomplete cycle (Muller and Carson, 1969; Muller and Jeletzky, 1970), which unconformably overlie the older rock groups. Each cycle grades upward from nonmarine coarse clastics to marine fine clastics. The fifth cycle has only the nonmarine coarse clastic stage. Five facies types are recognized within the Nanaimo Group and are named after the formation that best characterizes them.

The first depositional cycle is represented by the Comox and Haslam Formations respectively and the facies types are named after them. The Comox-type facies consists of interbedded quartzo-feldspathic clastics, is lacking in conglomerate, and contains interbedded carbonaceous shale and coal. This facies type contains the Nanaimo Basin coal measures and represents a swamp and lagoonal environment. The Haslam-type facies consists of thick, poorly bedded sandy shale and shaly sandstone with abundant fossils indicating nearshore deposition at shallow depths subject to wave action.

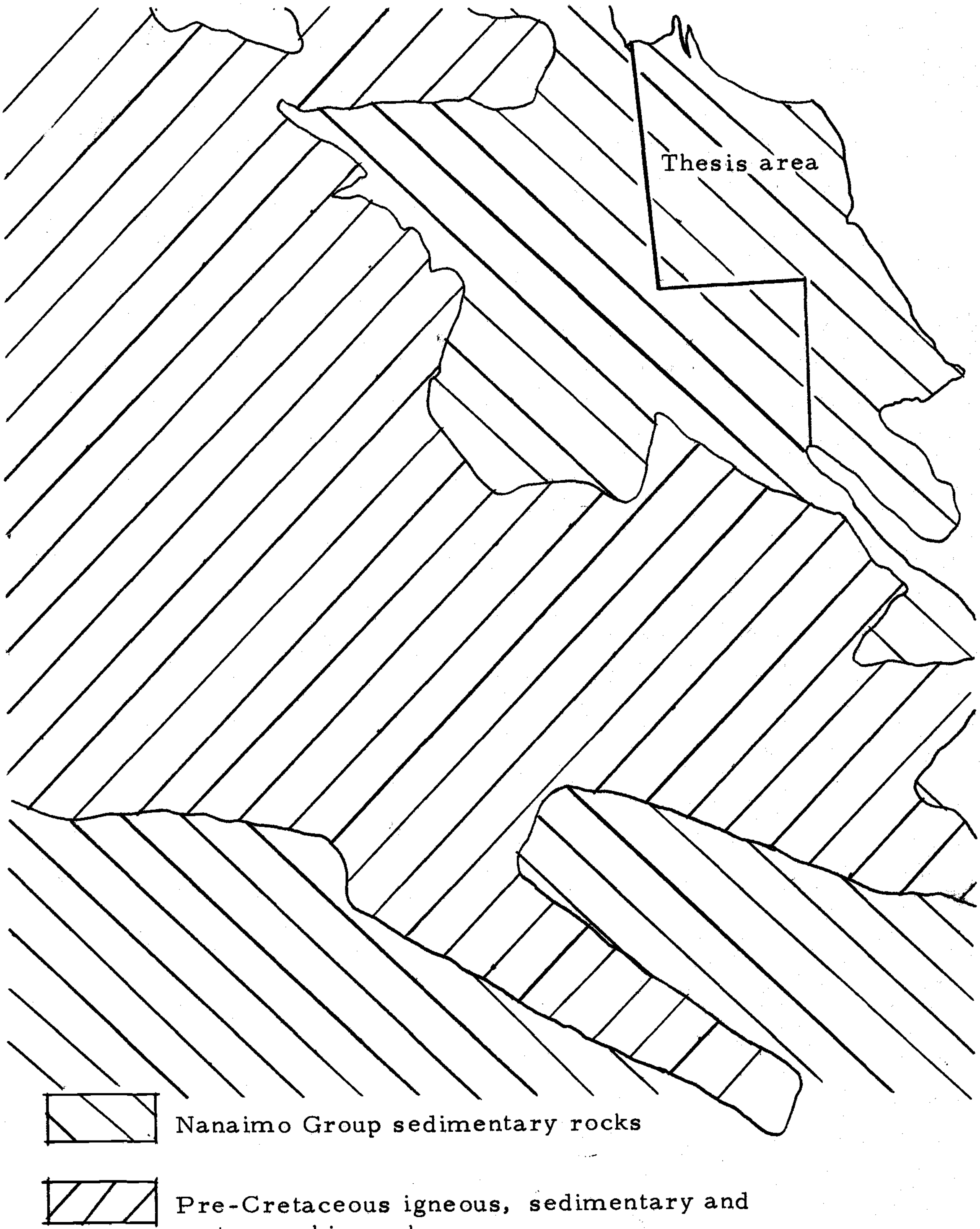


Figure 12. Distribution of outcropping pre-Cretaceous sedimentary, metamorphic and igneous rocks surrounding the Nanaimo Group sedimentary rocks and the thesis area (Muller and Jeletzky, 1970, Figure 11, Geologic Map of the Nanaimo Group, Vancouver Island and Gulf Islands, B. C.).

The second depositional cycle is represented by the coal-bearing Extension-Protection Formation and the Cedar District Formation with the respective facies types bearing their names. The Extension-type facies is made up of coarse clastic material--of interbedded conglomerate, pebbly sandstone and arkosic sandstone--and represents an environment of reworked delta and shore bar sediments. The Cedar District-type facies has been discussed extensively in the Stratigraphy section of this paper, but one additional comment will be interjected here. Muller and Jeletzky (1970) deny Usher's (1952) claim of having found a specimen of Bostrychoceras elongatum in the Cedar District Formation; rather they feel that it was derived from a limy concretion of the underlying Haslam Formation. If this is the case, then another source of Nanaimo Group sediments would be the sedimentary rock of older Nanaimo Group formations.

The third depositional cycle is represented by the De Courcy and Northumberland Formations of Extension-type facies and Cedar District-type facies respectively.

The fourth depositional cycle is represented by the Geoffrey and Spray Formations of the Extension type facies and the Cedar District-type facies respectively.

The incomplete fifth depositional cycle consists of the coarse clastic basal stage with the upper fine clastic phase missing. The Gabriola Formation of the Extension-type facies is the only representative.

The fifth facies type is the Benson, a fluvial conglomerate found only at the base of the Comox Formation. Clapp (1912a, b) originally thought that the Comox and Benson were separate formations, but recent studies (Muller and Carson, 1969) have shown them to be correlative, and the name Benson has been retained for the basal member of the Comox Formation.

The next recorded event was the exposure of the land mass to erosion in the Early Tertiary, accompanied by faulting and folding, discussed in the Structure section.

During the Pleistocene, Vancouver Island was covered by ice caps from two glacial epochs and the rocks of the Nanaimo Group were glacially scoured, leaving widely scattered glacial debris during the retreat. Principal movement of the glaciers was northwest to southeast (Clapp, 1914a).

Symons (1971), in a study of the paleomagnetism of the Jurassic Island Intrusions, notes the possibility of a 15° clockwise rotation of Vancouver Island since the mid-Jurassic. If rotation occurred, it was probably contemporaneous with the middle Cretaceous portion of the Nevadan Orogeny and resulted from the collision of a small Asian land mass with the North American plate (Wilson, 1968). On the other hand, rotation may have been related to the Tertiary folding and faulting of Vancouver Island, resulting from oceanic plate rotation and consumption under the North American plate as the two moved by each other (Symons, 1971). However, it must be remembered that these explanations for rotation (if indeed it occurred) are purely speculative and more detailed geologic and geophysical studies of the region will be necessary to support or discount them.

ECONOMIC GEOLOGY

Coal

Coal has been the principal mineral resource in the Nanaimo Basin for over 100 years. Mining operations started in 1852 and maximum production was attained in 1911 when 1, 184, 719 long tons (one long ton equals 2240 pounds) valued at four million dollars were produced (Clapp, 1914). A total of 72 million metric tons (one metric ton equals 2204. 7 pounds), ranked by the American Society for Testing of Materials as High volatile A bituminous, was extracted before operations came to a virtual standstill in the 1960's. The major mines are abandoned because of the difficulties created by having to carry out operations at depths of up to 2000 feet when more economic methods of producing energy are available. Without newer and less costly methods of extraction, the Nanaimo coal fields will remain economically unproductive (Muller and Carson, 1969).

Sand and Gravel

Minor sand and gravel operations have been carried out in the Nanaimo area, but only for local use in building construction, road-building and railroad beds.

Building Stone

The sandstones of the De Courcy Formation have furnished a fair quality of building stone in the past. Quarrying took place at Jack Point (adjacent to Duke Point), but no large operations have taken place since 1911.

Petroleum

Petroleum has never been produced from rocks of the Nanaimo Group, although the stratigraphy has been alluring to some companies. The Shell Oil Company (personal communication, Gerry Hill of Yellow Point Lodge), Chevron Standard Limited of Canada (personal communication, D. W. Organ, Chief Geologist), and the Union Oil Company of California (personal communication, Dr. Keith F. Oles) have shown an interest in reconnaissance and economic potential, but no successful drilling (if any) has been done to date.

SELECTED REFERENCES

Bell, W. A. 1957. Flora of the Upper Cretaceous Nanaimo Group of Vancouver Island, British Columbia. Geologic Survey of Canada, Memoir 293.

Clapp, C. H. 1912a. Geology of Nanaimo sheet, Nanaimo Coal Field, Vancouver Island, British Columbia. Geologic Survey of Canada, Summary Report 1911. p. 91-105.

________________ 1912b. Note on the geology of the Comox and Suquash Coal Fields. Geologic Survey of Canada, Summary Report 1911. p. 105-107.

________________ 1914a. Geology of the Nanaimo map-area. Geologic Survey of Canada, Memoir 51.

Clapp, C. H. and H. C. Cooke. 1917. Sooke and Duncan map-areas, Vancouver Island. Geologic Survey of Canada, Memoir 96.

Goddard, E. N. et al. 1951. Rock-color chart. New York, Geological Society of America. 11 p.

Hill, G. 1971. Owner of Yellow Point Lodge, Vancouver Island, British Columbia. Personal communication.

Jeffrey, W. G. and A. Sutherland-Brown. 1964. Geology and mineral deposits of the major islands on the British Columbia coast. Canadian Mining Journal. July.

Kendrew, W. G. and D. Kerr. 1951. The climate of British Columbia and the Yukon Territory. Ottawa, Queen's Printer. 222 p.

Koppen, W. P. 1931. Grundriss Der Klimakunde. Berlin. 388 p.

McKee, E. D. and G. W. Weir. 1953. Terminology for stratification and cross-stratification in sedimentary rocks. Geologic Society of America, Bulletin 64:383.

Muller, J. E. and D. J. T. Carson. 1968. Geology and mineral deposits of Alberni map-area, British Columbia. Geologic Survey of Canada, Paper 68-50.

Muller, J. E. and J. A. Jeletzky. 1967. Stratigraphy and biochronology of the Nanaimo Group, Vancouver Island and Gulf Islands, British Columbia. Geologic Survey of Canada, Paper 67-1B. p. 38-48. (Summary of Paper 69-25)

Oles, K. F. 1972. Associate Professor. Corvallis, Oregon State University. Personal communication.

Organ, D. W. 1971. Chief Geologist. Chevron Standard Limited of Canada. Personal communication.

Richardson, J. 1872. Coal fields of the east coast of Vancouver Island. Geologic Survey of Canada, Report of Progress, 1871-1872. Part 3, p. 73-100.

Shepard, F. P., R. F. Dill and U. Von Rad. 1969. Physiography and sedimentary processes of La Jolla submarine fan and fan-valley, California. American Association of Petroleum Geologists, Bulletin 53:39-420.

Sutherland-Brown, A. 1966. Tectonic history of the Insular Belt of British Columbia. Canadian Institute of Mining and Metallurgy, Special Vol. No. 8. p. 83-100.

Symons, D. T. A. 1971. Paleomagnetism of the Jurassic Island Intrusions of Vancouver Island, British Bolumbia. Geologic Survey of Canada, Paper 70-63.

Usher, J. L. 1952. Ammonite faunas of Upper Cretaceous rocks of Vancouver Island, British Columbia. Geologic Survey of Canada, Bulletin 21.

Williams, H., F. J. Turner and C. M. Gilbert. 1954. Petrography. San Francisco, Freeman. 406 p.

Wilson, J. T. 1968. Static or mobile earth: The current scientific revolution. Proceedings of the American Philosophical Society. Vol. 112.

APPENDICES

APPENDIX I

De Courcy Formation: Stratigraphic Section

Initial point and base of section: Northeast shore of Ladysmith Harbor: 300 yards N. 76° E. of the barn on the northeast side of Brenton Road, 0.5 miles southeast of the Code Road-Brenton Road intersection (Plate I). Commence at sharp break in slope upward 20 yards northeast of the fence bordering the cultivated field.

Terminal point and end of section: 1.1 miles N. 58° E. of initial point at the gentle break in slope downward. Exposures are poor and the traverse was measured mostly for thickness because it is the most complete section in the thesis area.

De Courcy Formation lies in fault contact with itself; the displacement of the fault being unknown.

Unit no.		Thickness (ft) Unit	Total
4	Covered dip slope: arbutus trees, low brush, tall grass and thick moss carpet cover the interval. Difficult to determine individual bed thicknesses because of cover. Granodiorite glacial erratics, very coarse-grained sandstones and pebble conglomerates litter dip slope on northeast side of Woodley Range. Conglomerate: poorly exposed 8 feet below crest of Woodley Range: color fresh, medium gray (N 5), weathered, dark yellow brown (10 YR 4/2); beds 4 to 7 feet thick containing pebbly sandstones and poorly sorted fine- to coarse-grained sandstone lenses 1 to 3 feet thick and 5 to 25 feet wide; cliff-former holding up cuesta. Contact: sharp scour-and-fill.	683	1355
3	Sandstone: color fresh, medium gray (N 5), weathered, dark yellow brown (10 YR 4/2); medium- to fine-grained, fair sorting, angular	8	672

Unit no.	Description	Thickness (ft) Unit	Total
	to sub-angular grains of quartz, mica and feldspar; featureless; cliff-former. Contact: sharp scour-and-fill.		
2	Pebble conglomerate: color fresh, medium gray (N 5), weathered, dark yellow brown (10 YR 4/2); cliff-former. Contact: mostly covered but sharp where exposed.	4	664
1	Sandstones: poorly exposed over uppermost 25 feet; below this interval all beds are completely covered by heavy vegetation or talus blocks of sandstone and conglomerate up to 6 feet in diameter from the overlying beds. Contact: covered and defined at sharp break in slope downward.	660	660

Cedar District Formation

APPENDIX II

Cedar District Formation: stratigraphic section

Initial point and base of section: axis of the Trincomali Anticline at low tide, 1040 feet north of Brightman Road dead-end, and N. 54° W. of the small rocky point on the southwest side of Round Island (Plate I).

Terminal point and top of section: 1.2 miles S. 5° E. of initial point and S. 37° W. of the small rocky point on the southwest side of Round Island.

De Courcy Formation

Contact conformable, sharp and gently undulating.

Cedar District Formation

The Cedar District Formation stratigraphic section is 992 feet thick and without definable boundaries that would allow one to break it down into mappable units. Therefore, the complete section will be treated as one unit and will be described from the top to the base.

The upper 82 feet are composed of medium dark gray (N 4) mudstones. The mudstones are laminated, but appear poorly bedded as a result of weathering, wave erosion, load deformation and intraformational slumping.

Sandstone dikes and sills appear in the 910 to 565 foot interval. They are light olive gray (N 7), fresh and weathered, and generally 6 to 14 inches in thickness. The grains of quartz and feldspar are fine- to medium-sand size, angular to sub-angular, poorly sorted, and calcite is the cement. The dikes and sills stand out as small ribs on a wave-cut platform. The lowermost sandstone dike in the section is worthy of note because of its size. It is 7 feet thick, light olive gray (N 7) fresh, and grayish orange (10 YR 7/4) weathered.

Micrite lenses 1/2 to 2 inches thick, 3 to 20 feet wide and 1 to 40 feet apart occur in the 900 to 100 foot interval. They appear to be closely associated with limy concretions up to 6 inches in diameter, some of which are fossiliferous.

The lowest 565 feet of the section is composed of mudstones similar to those in the upper 82 feet.

The entire section of the Cedar District Formation underlies a wave-cut platform with the sandstone dikes standing out as ribs and ledges.

The basal contact with the Extension-Protection Formation lies offshore in the Stuart Channel below low tide level.

APPENDIX III

De Courcy Formation: Stratigraphic section

Initial point and base of section: Northeast shore of Vancouver Island, 0.7 mi. S. 40° E. of Joan Point, S. 18° E. from power cable support on southwest shore of Mudge Island, and N. 80° W. from the Mudge Island-Link Island narrows.

Terminal point and top of section: 200 years west of the Joan Point warning light at the low tide mark.

Top of formation lies offshore in Northumberland Channel.

Unit no.	Description	Thickness (ft) Unit	Total
23	Pebbly sandstone: grayish orange (10 YR 7/4); beds 1-7 feet thick; coarse- to fine-sand, poorly sorted angular to well-rounded grains; pebbly sandstone concretions 6 inches to 5 feet in diameter scattered in random orientation; pebbly sandstone concretions 6 inches to 1 foot in diameter lie along bedding planes, traceable up to 70 feet along strike. Intercalated mudstone beds: medium dark gray (N 4); 3 to 5 inches thick. Intercalated sandstone beds: yellowish gray (5 Y 7/2) weathered; 1 to 5 inches thick; fine- to very fine-grained, well sorted, angular grains; parallel laminae and scour-and-fill (1/4 to 1 inch deep), load casts, intraformational slump showing paleoslope to the N. 70° E.; all contacts are sharp and planar, gently undulating. This unit underlies wave-cut platform east of the Joan Point warning light and is a ledge-former southeast of the warning light. Contact: with unit 22 sharp and planar.	48	447
22	Pebbly sandstone lenses: color and lithology as in unit 21; 2 to 12 feet wide and 4 to 11 inches thick; enclosed in sandstone: yellowish gray (5 Y 7/2); beds 1 to 12 feet thick; coarse- to medium-grained, poorly sorted, sub-rounded to	85	399

Unit no.	Description	Thickness (ft) Unit	Total
	angular grains; deeply weathered showing faint laminae; contacts, top and bottom, between pebbly sandstone lenses and enclosing sandstone beds are sharp. Intercalated mudstone beds: medium dark gray (N 4); 3 to 6 inches thick. Concretions as in unit 28, but not defining bedding planes. Contact with unit 21 very sharp and planar.		
21	Sandstone: yellowish gray (5 Y 7/2); 1 to 5 feet thick; medium- to fine-grained, poorly sorted, angular to sub-angular grains; more severely weathered than overlying units; honeycombing very prominent, concretions as in unit 27; sandstone and concretions are thinly laminated; blocky parting; scattered lenses of pebbly sandstone as in unit 22 with sharp top and bottom contacts. Intercalated mudstone beds 1 to 5 inches thick; weather into discoidal chunks 1/2 to 2 inches in diameter; sandstone-mudstone contacts sharp and gently undulatory; ledge-former. Contact with unit 25 sharp and planar.	40	314
20	Sandstone: color and lithology as in unit 21; beds 5 to 15 feet thick; laminated, concretions as in unit 22; blocky to slabby parting. A few pebbly sandstone lenses; the first appears at the 240 foot level and lenses become more common upward; ledge-former. Contact sharp and gently undulatory.	40	274
19	Sandstone: grayish olive (10 Y 4/2); thinly laminated; medium- to fine-grained, poorly sorted, angular to sub-angular grains, concretions as in unit 27; blocky parting; ledge-former. Contact sharp and planar.	10	239
18	Sandstone: grayish olive (10 Y 4/2); fine- to very fine-grained, good sorting, grains	10	229

Unit no.	Description	Thickness (ft) Unit	Total
	angular; thinly-laminated; platy parting; underlies wave-cut platform. Sharp planar contact.		
17	Sandstone: color and lithology as in unit 18; multiple scour-and-fill (up to 18 inches in depth); coarse-grained sandstone concretions 6 to 18 inches in diameter; platform-former. Contact: sharp and gently undulating.	15	219
16	Sandstone: grayish olive (10 Y 4/2); beds 1 to 2 feet thick; medium- to fine-grained, poorly sorted, angular grains; laminated, multiple scour-and-fill (up to 9 inches in depth); concretions as in unit 17. Intercalated mudstones: 1 to 3 inches thick; medium gray (N 4); ledge-former. Contacts with sandstones sharp and planar. Contact: sharp and planar.	20	204

Unit 15 represents an interval in which sandstone beds are thinner and mudstone beds thicker downward. The sandstones are moderate olive brown (5 Y 4/4), the mudstones are medium light gray (N 6). Sandstones are medium- to fine-grained, fair sorted and angular grains. The parting is platy and the contacts sharp. Thickness of beds (youngest to oldest) and structures only are listed. The sandstones stand out in relief on a wave-cut platform giving a ribbed appearance. Some of the sandstones act as ledge-formers.

Unit no.	Description	Unit	Total
15	Sandstone: 2 feet thick; laminated. Mudstone: 6 inches thick. Sandstone: 18 inches thick; laminated. Mudstone: 1 foot thick. Sandstone: 1 foot thick; all surfaces honeycombed; laminated. Sandstone: 3 feet thick; multiple scour-and-fill (up to 7 inches in depth). Sandstone: 5 feet thick; laminated. Mudstone: 3 inches thick. Sandstone: 8 inches thick; laminated. Mudstone: 1 inch thick. Sandstone: 4 feet thick; laminated.	40	184

Unit no.	Description	Thickness (ft) Unit	Total
	Sandstone: 4 feet thick; multiple scour-and-fill (up to 18 inches in depth). Mudstone: 3 inches thick. Sandstone: 1 foot thick. Mudstone: 3 inches thick. Sandstone: 5 feet thick; thinly-laminated; channels (up to 3 feet in depth). Sandstone: 2 feet thick; laminated. Sandstone: 1 foot thick; laminated. Mudstone: 3 feet thick. Contact: sharp and planar.		
14	Sandstone: grayish olive (10 Y 4/2); medium- to fine-grained, poorly sorted, angular to sub-angular grains; channels up to 7 feet in depth; concretionary and honeycombed; ledge-former. Contact: distinct, but irregular.	14	144
13	Sandstone-mudstone interbedded. Sandstones are grayish olive (10 Y 4/2); medium- to fine-grained, poorly sorted, angular to sub-angular grains; laminated. Mudstones are medium light gray (N 6). Mudstone-sandstone contacts are sharp and planar. Sandstone: 2 feet thick. Mudstone: 1 foot thick. Sandstone: 3 feet thick. Mudstone: 2-1/2 feet thick. Sandstone: 1 foot thick. Mudstone: 1 foot thick. Sandstone: 2-1/2 feet thick. Rib-formers on a wave-cut platform. Contact: sharp and planar.	14	130
12	Sandstone: very pale orange (10 YR 8/2); very fine-grained, well sorted, angular grains, laminated; concretionary; ledge-former. Contact: sharp and planar.	16	116

Unit no.	Description	Thickness (ft) Unit	Total
11	Sandstone-mudstone interbedded: colors and lithologies as in unit 13. Mudstone: 8 inches thick. Sandstone: 2 feet thick. Mudstone: 6 inches thick. Sandstone: 1-1/2 foot thick. Mudstone: 9 inches thick. Sandstone: 3 feet thick. Mudstone: 4 inches thick. Sandstone: 1 foot thick. Mudstone: 1 inch thick. Sandstone: 1-1/2 foot thick. Mudstone: 7 inches thick. Sandstone: 3 feet thick. Mudstone: 4 inches thick. Sandstone: 4 feet thick. Mudstone: 9 inches thick. Sandstone: 1-1/2 foot thick. Mudstone: 6 inches thick. Rib-formers on a wave-cut platform. Contact: sharp and gently undulatory.	22	100
10	Sandstone: very pale orange (10 YR 8/2); medium- to fine-grained, poorly sorted, angular to sub-angular grains; laminated; ledge-former. Contact: distinct and gently undulatory.	5	78
9	Sandstone: very pale orange (10 YR 8/2); medium- to fine-grained, poorly sorted, angular to sub-angular grains; laminated; ledge-former. Contact: sharp and planar.	2	73
8	Sandstone: very pale orange (10 YR 8/2); medium- to fine-grained, poorly sorted; angular to sub-angular grains; laminated; ledge-former. Contact: sharp and planar.	12	71
7	Covered: logs and sandstone, granodiorite to gabbro and conglomerate erratics. Interval probably similar to units below.	19	59

Unit no.	Description	Thickness (ft) Unit	Total
6	Mudstone: medium gray (N 5); 2 feet thick. Sandstone: very pale orange (10 YR 8/2); 1 foot thick; fine-grained, well sorted, angular grains; laminated; sharp planar contacts above and below; ledge-former. Mudstone: medium gray (N 5); 3 feet thick. Contact: sharp and planar.	5	40
5	Sandstone: very pale orange (10 YR 8/2); medium- to fine-grained, poorly sorted, angular grains; thinly laminated; ledge-former. Contact: sharp and planar.	6	35
4	Mudstone: medium gray (N 5); honey-combed; Sandstone: Intercalated beds; 1 to 6 inches thick; very fine-grained, well sorted, angular grains; spaced at intervals of 8 to 30 inches; rib-formers; contacts with mudstone are sharp and planar; rib-formers. Contact: sharp and planar.	20	29
3	Sandstone: very pale orange (10 YR 8/2); medium- to fine-grained, poorly sorted, angular to sub-angular grains; channels up to 2 feet in depth; ledge-former. Contact: sharp and planar.	3	9
2	Sandstone-mudstone interbeds: deeply weathered and deformed by intraformational slumping showing a paleoslope trending N. 65^{o} E. Contacts and lithologies are obscure within the unit. Contact: sharp and gently undulatory.	4	6
1	Sandstone: pale yellow brown (10 YR 6/2); medium- to fine-grained; poorly sorted, angular grains; ledge-former.	2	2

Contact at base of section with the Cedar District Formation is very sharp and gently undulatory. Units below are nearly solid mudstone with thin (1/4 to 1 inch) sandstone beds at intervals of 5 inches to 20 feet.