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Stratigraphy and basin evolution of the upper Hayes River
and Cochrane Bay groups, Island Lake Greenstone Belt,
northeastern Manitoba

University — Université

Carleton University, Ottawa, Ontario

Degree for which thesis was presented — Grade pour lequel cette thèse fut présentée

Master of Science

Year this degree conferred — Année d'obtention de ce grade

1984

Name of Supervisor — Nom du directeur de thèse

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STRATIGRAPHY AND BASIN EVOLUTION
OF THE UPPER HAYES RIVER
AND COCHRANE BAY GROUPS,
ISLAND LAKE GREENSTONE BELT,
NORTHEASTERN MANITOBA

By

KATHRYN L. NEALE

A thesis submitted to the Faculty
of Graduate Studies and Research
in partial fulfillment of the
requirements for the degree
Master of Science

Department of Geology

Carleton University

Ottawa, Ontario

May, 1984

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ABSTRACT

In the northwestern part of the Island Lake Greenstone Belt (Archean), the Hayes River Group comprises volcanic and pyroclastic rocks conformably overlain by meta-sedimentary rocks. Strata of this group have been intruded by tonalitic plutons. The Hayes River Group and the plutons are disconformably/non-conformably overlain by sedimentary rocks of the Cochrane Bay group.

Marine deposits in the upper Hayes River Group include: sand-rich beds of classical turbidites; channel-fill conglomerate (derived by erosion of the turbidites) of probable mass-flow origin; and interstratified siltstone-argillite couplets interpreted as levee and interchannel deposits.

Two successive non-marine cycles, each consisting of two main facies, have been identified in the lower Cochrane Bay group. Both cycles evolved from an arkosic, mid-alluvial fan to a feldspathic, fluvial (and in places supratidal) setting.

Marine deposits of the upper Cochrane Bay group occur in unbroken stratigraphic sequence, above the non-marine facies. The basal part of these deposits consists of a thinning- and fining-upward transition from pebble-bearing wacke, through sand-rich beds of classical turbidites, to rhythmic siltstone-argillite couplets. This succession is compatible with deposition in a mid-fan submarine channel, transitional upward to a basin plain sequence.

ACKNOWLEDGEMENTS

I would like to extend my sincere thanks to my supervisor, Dr. J. A. Donaldson, for critically reading earlier versions of the text, and providing many comments for its improvement. I am also indebted to Dr. W. Weber of the Manitoba Department of Energy and Mines, who suggested this study and donated much of his time to helpful discussions.

I wish to express my thanks to M. T. Corkery, H. P. Gilbert, C. R. McGregor and Dr. P. Theyer (members of the Manitoba Mineral Resources Division), and Dr. R. K. Herd of the Geological Survey of Canada; all of whom provided constructive comments and discussion. Capable field assistance was rendered by S. Boden, R. P. Dmytriw, R. Gaba, D. J. Grimes, C. M. Hodgson, B. Martin and D. Petras.

The financial and logistical field support of the Manitoba Department of Energy and Mines is gratefully acknowledged. This department also provided chemical analyses and numerous thin sections.

I am grateful to F. R. Agnew, S. D. Carr and L. S. Lane, for their advice and suggestions pertaining to development of the photographs. My thanks to D. A. MacKean for her drafting of figure 5.1. Special thanks are extended to J. F. Linton, S. B. Linton, J. E. Neale, K. M. Neale and S. L. Pratt; all of whom patiently helped colour six copies of my geological map.

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Chapter I

INTRODUCTION

Statement of Problem

Within the Island Lake Greenstone Belt, clastic rocks deposited during the late stages of sedimentation (relative to the Hayes River Group sediments) are exposed in two main areas, namely: Cochrane Bay in the northwest part of Island Lake, and the Sinclair and Savage Islands in the east-central part of the Lake (Figure 1.2). The current study initially focused on both these areas, because a precise formational or group definition of the sedimentary rocks has not been established (Neale and Weber, 1981a).

For example, sedimentary rocks in the Sinclair Islands area were originally defined as, and represent the type area of, the "Island Lake Series" (Wright, 1928, p. 71). Wright assigned the Cochrane Bay--Garden Hill sediments to a class within the older "Hayes River Group". Godard (1963a), however, claimed that sediments at both localities are part of the Island Lake Series. From this contradiction arises the question: what stratigraphic relationships or characteristics of the two sedimentary areas justifies their separation from each other, and from the underlying Hayes River Group?

Wright (1932b) considered strata in the type area of the Island Lake Series to be Proterozoic: "an angular and erosional unconformity in the Sinclair Islands area is suggested by an exposure of strongly foliated magnesian basalt of the Hayes River Group in contact with gently dipping pebble conglomerate of the

Island Lake Series (station #543, Figure 1.2). In addition, Godard (1963a) indicated an angular unconformity on Loonfoot Island (eastern area). In the Cochrane Bay area, however, the younger succession of sedimentary rocks appears to be concordant with the underlying Hayes River Group (erosional unconformity only). The present study focuses on the sediments in the western area, and because of the structural and lithological (see p. 24-25) differences that occur between the eastern and western sections, the younger metasedimentary rocks in the northwest part of Island Lake are herein (Chapters 2-5) referred to as the "Cochrane Bay Group".

Location

The Island Lake area, northeastern Manitoba, is bounded by $54^{\circ}30'$ and 54° north latitudes, and $93^{\circ}30'$ and 95° west longitudes. The eastern extremity (Sagawitchewan Bay) is crossed by the Manitoba-Ontario boundary (Figure 1.1), approximately 600 kilometres north-northeast of Winnipeg.

The study area, in the northwest part of Island Lake, centres around Cochrane Bay (Figures 1.2 and 1.3) and includes parts of N.T.S. 53E/15 NE, 15 NW and 15 SE (Township 57, Ranges 19 and 20 E, and Township 56, Range 19 E). The easiest access to the field area is provided by the nearby community of Island Lake, on Stevenson Island in the west-central section of the lake, separated by a channel from the Garden Hill Indian Reserve. The airport on Stevenson Island is served by scheduled commercial flights from Winnipeg and from Thompson, Manitoba.

Figure 1.1 Location of study area within the Island Lake Greenstone Belt.

Previous Work

The Island Lake area was first explored geologically in 1878 by A. S. Cochrane, whose work led to publication of a shore-line map and a brief report on the general geology (Bell, 1880).

In 1927, the area was mapped by J. F. Wright, whose results were published (Wright, 1928) as a report and map sheet at a scale of two miles to the inch. Wright proposed the first stratigraphic column for the area, naming the oldest unit the Hayes River Group. He included lithologically similar sediments and lavas at several localities (Table 1.1) within the Hayes River basin of northeastern Manitoba (Wright, 1926, summarized in 1932b). With regard to Island Lake, Wright inferred the lowest exposed units of this group to be sedimentary rocks, overlain by intercalated basic volcanic and sedimentary rocks, which in turn are succeeded by basic volcanic rocks and derived schists (Table 1.1).

Wright also recognized a younger succession of sedimentary rocks, named by him the Island Lake Series, inferred to have been deposited on a planation surface of the Hayes River Group (Wright, 1928, p. 72). He restricted usage of the name, Island Lake Series, to the commonly coarse, clastic sediments in the east-central part of the lake (Figure 1.2). Wright nowhere saw the Hayes River Group and Island Lake Series in contact (since observed by Neale and Weber, 1981a, p. 39), but he noted (Wright, 1928, p. 72):

- i) an average dip of 40 degrees for the strata of the

Table 1.1 Summary of work in the Gods
Oxford Lake and Cross Lake
of Godard (1963a,b). After

ake, Island Lake,
ea before the work
arrison (1951).

Wright (1928) Island Lake Area	Wright (1932A) Oxford House Area	Wright (1932B) Gods-Island-Oxford	
Diabase	Diabase	Diabase	I
Intrusive Contact	Intrusive Contact	Intrusive Contact	
Pegmatite and aplite		Aplite, pegmatitic granite and pegmatite	
Granite, granite-gneiss quartz diorite quartz gabbro	Granitic intrusions	Granite-granodiorite	C
Granite porphyry		Quartz & feldspar porphyry	
Intrusive Contact	Intrusive Contact	Intrusive Contact	
Diorite and gabbro	Gabbro	Gabbro and diorite	
<hr/>			
Intrusive Contact		Intrusive Contact	
Island Lake Series quartzite, grit and conglomerate	Intrusive Contact	Island Lake Series conglomerate, grit and quartzite	I
		Unconformity	
<hr/>			
	Oxford sediments slate, greywacke, quartzite, arkose and conglomerate	Oxford sediments conglomerate, arkose, quartzite, slate and sericitic schists	C
<hr/>			
	Unconformity		
Unconformity	'Quartz-eye' granite	Unconformity	U
	Intrusive Contact		
<hr/>			
Hayes River Group andesite, dacite, tuff and derived schists	Hayes River Group basalt, andesite, trachyte, tuff, iron formation, chert, mica schist, chloritic and sericitic schists	Hayes River Group basalt, andesite, dacite tuff, iron formation, chert, chloritic and sericitic schists	H
andesite, dacite, tuff, slate, cherty quartzite			U
slate, greywacke, quartzite and conglomerate			T

Horwood (1935) Cross Lake Area	McMurchy (1944) Island Lake Area	Quinn (1960) Island Lake Area
base	Diabase	Diabase, gabbro
intrusive Contact	Intrusive Contact	Intrusive Contact
		Pegmatite, aplite and muscovite granite
granite, granite-gneiss	Granite, granite- gneiss	Granite, granodiorite, quartz monzonite and allied rocks; minor syenite and quartz diorite
	Intrusive Contact	Intrusive Contact
	Diorite and gabbro	Peridotite, pyroxenite and minor serpentinized volcanic rocks
		Granite-gneiss mixed gneisses, hybrid gneiss lit-par-lit gneiss and migmatite
intrusive Contact	Intrusive Contact	Intrusive Contact
Island Lake Group conglomerate, arkose, greywacke, argillite; minor andesite	Island Lake Series grit, arkose, grey- wacke, quartzite, and conglomerate	Island Lake Series arkose, arkosic quartzite conglomerate
unconformity	Unconformity	Disconformity
Hayes River Group andesite; minor conglomerate, tuff, breccia and iron formation	Hayes River Group basalt, andesite, dacite and minor rhyolite	Hayes River Group greywacke, arkose, argillite, quartzite, slate, conglomerate and iron formation
unconformity		
light gneiss	tuffs, chert, iron formation, cherty quartzite, grey- wacke, arkose and conglomerate	basalt, andesite, dacite, minor rhyolite, trachyte, chert, iron formation, jasper, tuff and agglomerate

Figure 1.2 Distribution of the Isl
ing to Wright (1928), Q
(1963a,b). Station num
the text.

Lake Series accord-
n (1960) and Godard
s are referenced in

94°50'
54°02'

LEGEND

Wright (1928)	Island Lake Series	▲	Haves River Group sediments	▲
Quinn (1960)	Island Lake Series	■	Haves River Group sediments	■
Godard (1963a,b)	Island Lake Series	●	Haves River Group sediments	●
Station #1021	Shoreline locations of arkosic wacke (+/- conglomerate) overlying tonalite (after Herd and Ermanovics, 1976).			
#1043				
#1103				

Geological contact (defined, approximate)

93°43'
94°02'

Island Lake Series, whereas rocks within the Hayes River Group generally dip 70 degrees or over (structural discordance).

- ii) an abundance of clasts of various Hayes River lithologies in the basal conglomerate of the Island Lake Series (erosional unconformity).

In addition, Wright's (1926) work in the Oxford and Knobs Lakes area allowed him to compare the Oxford sediments (Table 1.1) with the Island Lake Series (Wright 1932a,b). He considered the Island Lake Series to be Proterozoic, much younger than the Oxford sediments. According to Wright (1932b):

- i) the Oxford sediments are more widespread than the Island Lake Series
- ii) the Island Lake Series is much less deformed than the Oxford sediments, and is not intruded by granitoid bodies
- iii) there is a more marked structural discordance between the Island Lake Series and the Hayes River Group at Island Lake than between the Oxford sediments and the Hayes River Group at Oxford and Gods Lakes

In 1938, McMurphy (1944) remapped the Island Lake area at a scale of four miles to the inch. He revised the stratigraphic sequence (Table 1.1), and suggested that some of the sedimentary rocks, designated by Wright as part of the Hayes River Group, should be included in the Island Lake Series.

In 1956, Quinn and Meinert (1959) mapped the Island Lake

Series as defined by Wright in detail, and deduced that it disconformably overlies the Hayes River Group, rather than being in angular 'and' erosional discordance as reported by Wright (1928). They referred to isoclinal folding in the Hayes River Group, and although they did not clearly state whether such folding pre-dates or post-dates sedimentation, they did argue that the stratigraphically lowest part of the Island Lake Series and the highest part of the Hayes River Group are "reasonably" conformable (ibid., p. 25). Quinn and Meinert (op. cit., p. 24) maintained that a synclinal axial trace, characteristic of the Island Lake Series, passes into the Hayes River Group at the east end of the structure and can be traced for "some" distance. The Hayes River Group displays isoclinal folds beyond the borders of this major syncline. The main implications of their inferred disconformity are:

- i) some erosion of the Hayes River Group took place in pre-Island Lake time, but the major sediment sources were postulated to be granitoid and dioritic masses.
- ii) the Hayes River Group in pre-Island Lake time was relatively horizontal, possibly representing a shallow basin that was a precursor to the basin into which the Island Lake Series was deposited.

Quinn (1960) also produced a preliminary map for the Geological Survey of Canada, at a scale of four miles to the inch. In contrast to Wright (1928), Quinn concluded that most Hayes River sedimentary rocks are younger than the volcanic rocks (Table 1.1), and that much sedimentary rock near Garden Hill

assigned to the Hayes River Group, actually may be time-equivalent to the Island Lake Series (Figure 1.2).

In 1958 and 1959, Godard (1963a,b) produced three map sheets (59-3A, 59-3B and 60-2) at a scale of one inch to one mile (1:63,360). In agreement with Quinn and Meinert (op. cit.), he stated that the succession of sedimentary rocks overlying and intercalated with volcanic rocks, known as the Hayes River Group, is disconformably overlain by sedimentary rocks of the Island Lake Series (Table 1.2). An exception to this proposed disconformity is in the Loonfoot Island vicinity, where Godard inferred an angular unconformity (1963a, p. 34). Godard extended the Island Lake Series westward to include sedimentary rocks in the Garden Hill--Cochrane Bay area (Figure 1.2), which previously were designated as Hayes River Group rocks. However, in the western area, Godard noted a scarcity of structural and lithological similarities to sedimentary units in the east-central section of the lake (Sinclair and Savage Islands). He therefore argued that sedimentary rocks outside the type area (as defined by Wright, 1928) cannot be assigned to the Island Lake Series with absolute conviction (Godard, 1963a, p. 5).

In 1974 and 1975, work supported by the Geological Survey of Canada (Ermanovics, 1975; Ermanovics et al., 1975; Herd and Ermanovics, 1976) included mapping at a scale of 1:63,360 (Herd and Ermanovics, in preparation) and investigation of the structural problems within the Island Lake belt (Fyson et al., 1978; Park and Ermanovics, 1978; Park, 1981; see "Structural Geology").

Table 1.2 Table of Formations, Island Lake (Godard, 1963a).

RECENT AND PLEISTOCENE		Silt, clay, sand, gravel, boulder and boulder-clay deposits
G R E A T U N C O N F O R M I T Y		
P R E C A M B R I A N	INTRUSIVE ROCKS	10 Diabase, lamprophyre 9 Pegmatite, aplite, quartz porphyry, quartz-feldspar porphyry 8 Granite, granodiorite, tonalite and allied rocks, massive to gneissoid, minor porphyritic phases 7 Granitic Gneiss Complex: granitic gneiss, hybrid gneiss, paragneiss, lit-par-lit gneiss, migmatite 6 Gabbro, diorite and associated rocks 5 Peridotite, pyroxenite and serpen- tinized equivalents
	Intrusive Contact	
	ISLAND LAKE SERIES	4 Arkose, subarkose, greywacke, sub- greywacke, argillite, slate, proto- quartzite and affiliated schists 3 Conglomerate
	Unconformity	
	HAYES RIVER GROUP	2 Greywacke, subgreywacke, argillite, slate and derived schists, minor chert, conglomerate, flows, tuffs, tuffaceous sediments, iron forma- tion and pyroclastic rocks 1 Massive and pillowed andesite, dacite, basalt and derived schists, subordinate to minor acidic flow rocks, volcanic breccia, agglomer- ate, tuff and sediments Gabbroic, dioritic and amphibolitic intrusives, mainly sills

With respect to the supracrustal rocks, Herd and Ermanovics (op. cit., p. 393) concluded that all regions of volcanic and sedimentary rocks in the northern half of the Island Lake map-area (i.e., Stevenson Lake -- Collins Bay, Island Lake, Wapus Bay, Bigstone -- Knight -- Picket Lakes) probably were once continuous (see their Figure 83.1; disputed by Theyer, 1980b, p. 39). Field work by Ermanovics et al. (op. cit.) culminated in the recognition of a lower predominantly volcanic sequence, and an upper predominantly clastic sedimentary sequence in each belt. In the Island Lake belt, Herd and Ermanovics (op. cit.) referred to these sequences as Hayes River Group and Island Lake Series respectively (after Godard's definition, 1963a,b). These workers pointed out that the relationship between the two successions is uncertain.

Herd and Ermanovics (op. cit.) identified three shoreline locations, (Figure 1.2) where conglomerate of the Island Lake Series appears to unconformably overlie quartz diorite - granodiorite. For example, on the south shore of Cochrane Bay, they initially recognized a 1 to 2 metre thick regolith of angular vein quartz and tonalite clasts set in a rusty, arkosic wacke matrix. The regolith, grading downward into fractured and altered plutonic rock, grades upward into conglomerates rich in tonalite detritus.

Recent Work

Mineral deposit studies in the Island Lake area have been undertaken by Theyer (1977, 1978, 1979, 1980a,b, 1981, 1982), who

emphasized the stratigraphic position of the ultramafic rocks. In many cases, these rocks occur at the interface between the primarily volcanic rocks of the Hayes River Group and the sedimentary rocks of the Island Lake Series. According to Stewart (1980) and Theyer (1980a,b), this volcanic—sedimentary interface provided the locus for mineralization of the Island Lake Gold Mine (Figure 1.2). Theyer has proposed that the ultramafic rocks of the entire belt warrant base metal exploration, because they are apparently stratabound with respect to the volcanic/sedimentary contact. Inferences that at least some of the ultramafics are extrusive arise from Theyer's documentation of two, and possibly three, spinifex-textured ultramafic bodies. The origin of additional ultramafic rocks remains an important question, because if such rocks represent shallow intrusions introduced along post-volcanic faults, they have no place in a stratabound model.

Because the nature and position of the contact between the two main rock successions remained poorly documented, mainly because of the controversy regarding the definition and extent of the Island Lake Series (Wright, 1928; Quinn, 1960; Godard, 1963a), a 1:20,000 remapping project was initiated in 1981 (Neale and Weber, 1981a), and was continued in subsequent years (Weber et al., 1982a; Gilbert and Weber, 1983).

In 1981, field work was concentrated on the clastic sedimentary rocks of the "Island Lake Series" (Wright, 1928; Quinn and Meinert, 1959; Godard, 1963a). The two areas of focus were: Cochrane Bay in northwestern Island Lake, and Sinclair and

Savage Islands in the east-central section of the lake (Figure 1.2). The results of mapping in these areas are described by Neale et al. (1982) and by Neale (1981) respectively.

On the south shore of Cochrane Bay, Neale and Weber (1981a) observed several occurrences of tonalite (unit 6a)¹ overlain by regolith (10a, 10b)¹, one of which was reported by Herd and Ermanovics (1976, p. 393; see "Previous Work"). Interpreted as alluvial mid-fan sediments, units 10a, 10b, 10c, 10e and 10o¹ (characteristic of the south shore) were at first thought to be younger than the remainder of the Cochrane Bay sequence. However, additional mapping proved them to be transitional into unit 10r¹ (dominant on the southwest-trending extension of Cochrane Island) on the islands 200 m north of the south shore (e.g., Long Island), thereby placing them at the base of the Cochrane Bay group (Table 1.3). On the southeast shore of Cochrane Island (station #53, Figure 1.2), classical turbidites (units 11b and 11c)¹, interpreted by Godard (1963a) as part of the Hayes River Group, stratigraphically overlie the alluvial -- supratidal succession (Unit 10)¹, representing a deepening of the basin.

In the Sinclair and Savage Islands area, rocks originally defined as "Island Lake Series" by Wright (1928), comprise conglomerates, wackes and laminated siltstone-argillite couplets which are interpreted as glaciofluvial - glaciolacustrine deposits (Neale and Weber, 1981a). At the base of the meta-sedimentary succession, on the second island west of East Savage Island (station #543, Figure 1.2), an exposure of schistose and

¹ Units refer to Figure 2.1 in back pocket.

carbonatized magnesian basalt (unit 2a)² is in contact with matrix-supported, pebble-cobble conglomerate (4k)². Based on the undulating nature of this contact, the contrast between foliated and massive conglomerate, the proximity of banded iron formation, and the presence of basaltic clasts in the conglomerate, this contact may represent an inlier of the Hayes River Group unconformably (angular and erosional) overlain by conglomerate of the Island Lake Series.

In 1982 and 1983, preliminary geological maps of the western half of the Island Lake belt were published (Figure 1.3) at a scale of 1:20,000. A suggested series of events is outlined in Table 1.3. [With respect to unit 10, the unit numbers (i.e., 10a, 10b, 10c,...) described in this thesis do not correspond with the units named on the 1982 and 1983 maps, and hence the present and former unit numbers are shown in the appendix].

Of particular interest is the proposition by Gilbert (in Weber et al., 1982a, p. 35) that the Early Supracrustal Rocks (Units 1-5)¹ have been "isoclinally folded during the first period of deformation". He suggested that the first phase of deformation was 'synchronous' with intrusion of the Early Plutonic Rocks (Gilbert et al., 1983a). This view contrasts with that of Fyson (in Herd and Ermanovics, 1976, p. 397) who stated that "intrusion of plutons was earlier than both the fabric-forming deformations" (D₁ and D₂).

The Garden Hill conglomerate (Unit 5)¹, which had been assigned to the Island Lake Series by Quinn (1960; Godard,

² Units refer to Man. Min. Res. Div. Preliminary Map 1981 I-2.

Figure 1.3 Map of the western half of Island Lake showing the geological coverage completed in 1982 and 1983 (N.T.S. 53E/15; 1:20,000) with Preliminary Map identification (after Weber et al., 1982a). Shaded portion depicts area selected for thesis study.

Table 1.3 Table of Formations, Island Lake (western half).
Modified from Weber et al. (1982a), and Gilbert
and Weber (1983).

ARCHEAN	PROTEROZOIC	16	Molson dykes
	Post-Tectonic Plutonic Rocks	15	Granites (intruding Chapin Bay tonalite)
		14	Plagioclase & quartz porphyry dykes
		13	Mafic dykes, metamorphosed
	Late Plutonic Rocks	12	Tonalite, quartz diorite, felsic to intermediate dykes
		INTRUSIVE CONTACT	
	Late Metasedimentary Rocks "CUCHANE BAY GROUP"	11	Turbidity current deposits: wacke, siltstone, argillite
		10	Regolith: wacke, breccia (on unit 6); fluvial deposits: cross-bedded wacke, siltstone, tonalite- and volcanic-derived conglomerate
		UNCONFORMITY	
		9	Felsic metavolcanic rocks, related metasedimentary rocks, subvolcanic porphyries
ARCHEAN		8	Mafic intrusive rocks, minor related felsic phases
		7	Ultramafic intrusive, subvolcanic or flow rocks
	Early Plutonic Rocks	6	Tonalite batholiths (Bella Lake, Waasagomach, Chapin Bay, Pitch Pipe Island), related rocks
		INTRUSIVE CONTACT	
		5	Conglomerate, mainly sedimentary-derived
		4	Wacke, siltstone, argillite, conglomerate, chert, iron formation, carbonate
		3	Wacke, conglomerate, derived from felsic to intermediate pyroclastic deposits, interlayered with siltstone and argillite; iron formation
		2	Felsic to intermediate metavolcanic rocks: flows, pyroclastics, and related subvolcanic porphyries
		1	Mafic to intermediate metavolcanic rocks: flows, tuffs, breccias and related subvolcanic gabbro sills
	Early Supracrustal Rocks "HAYES RIVER GROUP"		

1963a), is remapped as part of the Early Supracrustal Rocks because: 1) it is locally interstratified with wackes and

argillites of unit 4

ii) it contains matrix and clasts which are compositionally similar, and resemble unit 4

lithologies

Unit 5 contains volcanic and plutonic detritus (<10%), external to the sedimentary succession (Units 3, 4 and 5)¹, indicating a brief interruption in the otherwise uniform deposition of strata.

A second cycle of felsic volcanism has been proposed (Unit 9)¹ because these rocks are lithologically different and spatially separated from felsic metavolcanic rocks of unit 2¹. East of Linklater Island, unit 9b¹ was previously interpreted as "quartz pebble conglomerate" (Theyer, 1978, p. 107), but zones which are distinctly aphyric, flow-banded, feldspar-quartz phyrlic, or contain lapilli-size quartz and felsic fragments, are more typical of an ash flow deposit, or of talus associated with a brecciated felsic dome.

General Geology

The Island Lake map-area is underlain by Precambrian rocks, the stratified units of which trend slightly north of west. Stratigraphic sequences of former workers (Wright, 1928; McMurchy, 1944; Quinn, 1960; Godard, 1963a,b), have been summarized in "Previous Work"; discussion here is restricted to the shoreline geology within the field area (Figure 1.3).

Continuous geological mapping on 1:20,000 scale has been completed only in the western half of the Island Lake belt (Neale

and Weber, 1981a; Weber et al., 1982a; Gilbert and Weber, 1983). The Table of Formations, employed here to display the general geology (Table 1.3), therefore, is applicable solely to the western region, and present geological information is insufficient to determine the eastward extension of these units. For example, figures GS-7-2 and GS-11-1, of Weber et al. (1982a) and Gilbert and Weber (1983), delineate the Late Metasedimentary Rocks (Units 10 and 11)¹ as part of the tentatively proposed "Island Lake Group", which implies a correlation with the type area of the Island Lake "Series" (Wright, 1928) in the east-central section of the lake (Sinclair and Savage Islands, Figure 1.2).

Reclassification of the "Island Lake Series" in the 'type area' as "Island Lake Group" is endorsed here, because the succession is not a time-rock unit [Wright (1928, p. 71) actually referred to the "Series" as a "group" of strata in his original definition]. However, metasedimentary rocks in the western area (Cochrane Bay, Figure 1.2) were not included in the original definition of the Island Lake Series; they were originally assigned to the Hayes River Group (Wright, 1928; Quinn, 1960), and were not designated as Island Lake Series until the work of Godard (1963a). Therefore, metasedimentary rocks of the Cochrane Bay area are informally referred to herein as the "Cochrane Bay Group"; a redefinition which is based primarily on lithologic dissimilarities observed between Cochrane Bay and Sinclair Islands areas (Neale, 1981; Neale et al., 1982).

Structural Geology

Although several authors (Wright, 1928; Quinn and Meinert, 1959; Godard, 1963a,b; Ermanovics et al., 1975; Weber et al., 1982a; Gilbert et al., 1983a) have commented on the structural geology of the Island Lake area, the most systematic studies are those of Fyson (in Herd and Ermanovics, 1976), Fyson et al. (1978), Park and Ermanovics (1978), and Park (1981), all of which are based on the stratigraphy according to Godard (1963a).

Observations in 1975 by W. Fyson and T. Rivers (Herd and Ermanovics, 1976; Fyson et al., 1978), which were limited to Collins Bay, Cochrane Bay, and eastern portions of the lake, culminated in the following suggested sequence of events for the structural development of the entire belt:

- (1) Deposition of mafic to felsic volcanics, tuffs, wackes and argillites of the Hayes River Group.
- (2) Emplacement of widespread tonalite - granodiorite plutons (e.g. Bella Lake) with offshoots intruding the Hayes River Group. As evidence, Fyson (in Herd and Ermanovics, 1976) referred to granitoid veins containing two foliations which he equated with the two main phases of deformation (D_1 and D_2), and a steep intersection lineation, L_2 , all of which are traceable across one deformed contact of granodiorite with sedimentary rocks. Fyson's conclusion, comparable to that of Quinn and Meinert (1959), is that the intrusion of plutons 'pre-dates' both fabric-forming deformations. This view conflicts with that of Ermanovics et al. (1975, p. 314), who placed the granodiorite

intrusion 'between' F_1 and F_2 . However, Ermanovics subsequently modified his view before publication of Fyson et al. (1978).

(3) Deposition of coarse clastic sedimentary rocks of the Island Lake Series. Fyson (in Herd and Ermanovics, 1976, p. 397) claimed that "internal fabrics within clasts are 'rare', as should be expected if the plutons were intruded before D_1 and D_2 deformations". In the same paper (p. 393), Herd and Ermanovics used identical evidence to conclude that "deformation preceded the deposition".

The conclusions summarized above were based mainly on observations of the Island Lake Series in the western half of the lake, namely, those sedimentary rocks which were assigned to the Series only by Godard (1963a; Figure 1.2). To the east, in the type area of the Island Lake Series (Wright, 1928; Figure 1.2), conglomerate exposed on the Sinclair Islands (unit 4m)² contains strongly foliated granitoid clasts in excess of 20% total clasts (Neale and Weber, 1981a). Clearly, this percent does not correspond with "rare" occurrences of foliated granitoid clasts. The present author suggests that intrusion of the plutons could have pre-dated both D_1 and D_2 (Fyson in Herd and Ermanovics, 1976; Fyson et al., 1978) only if:

- 1) the foliated clasts were derived from the basement to the supracrustal rocks, either from an exotic source or by complete erosion of the lower volcanic sequence

OR

- ii) the type area of the Island Lake Series is

significantly younger (post-pluton deformation, D_2) than the sediments of Cochrane Bay, where foliated clasts of tonalite - granite composition are in fact "rare".

(4) Renewed uplift of plutons and marginal subsidence caused the conglomeratic beds (e.g., units 10a, 10c and 10e)¹ to dip 30-50° away from the underlying Bella Lake tonalite (6a)¹, thereby forming large homoclines (D_0). In Cochrane Bay, major F_1 folds (e.g., through Nelson and Miller Islands, Figure 2.1 in back pocket and Figure 2.4) lie at high angles to, and apparently terminate against, the homocline on the south shore. This suggests that the homoclines evolved before the F_1 folding.

(5) Regional deformation D_1 occurred, with development of F_1 folds characterized by northwest- to west-trending steep axial surfaces. S_1 axial planar schistosity is mainly defined by oriented muscovite, but it is only locally developed and commonly is difficult to distinguish from subparallel F_2 foliation. Fyson (in Herd and Ermanovics, 1976) also noted a paucity of small-scale F_1 folds; these folds plunge at low angles, suggesting that bedding was nearly horizontal before D_1 deformation.

(6) Regional deformation D_2 followed, with small-scale folding about sub-vertical axial surfaces S_2 . S_2 foliation is more widespread than S_1 and where S_1 is present, S_2 is a crenulation cleavage. In the absence of S_1 , S_2 is commonly a phyllitic cleavage defined by the alignment of muscovite, and is not readily distinguishable from S_1 .

The S_2 foliation and axial traces of F_2 folds strike

predominantly eastward. Steeply plunging F_2 axes and axial lineations are attributed to the intersection of S_2 with steep beds and S_1 . One of the few large-scale F_2 folds forms the east-trending arm of Cochrane Island.

(7) A metamorphic peak, evidenced by cordierite and biotite at the east end of Cochrane Bay, was attained near the end of or after D_2 deformation. S_2 foliation is overprinted by randomly oriented porphyroblasts of biotite and cordierite, indicating that growth was after D_2 . Metamorphism is possibly related to intrusion of the late granites (Unit 15)¹.

(8) Occurrence of local F_3 folding about north-northeast vertical axial surfaces S_3 . Some of the F_3 folds form northeast- and northwest-trending conjugate sets. D_3 structures are most pronounced along major north-northeast lineaments, and may have provided the fracture system for the Molson diabase dykes (Proterozoic Unit 16) which occupy such zones (Ermanovics and Fahrig, 1975).

Chapter II

LITHOLOGIC DESCRIPTIONS AND INTERPRETATION

Background

The area studied regionally is in the western part of Island Lake; the thesis study area, within which 1:20,000-scale mapping was carried out systematically, centres around Cochrane Bay (Figure 2.1 in back pocket).

Individual lithologies encountered during mapping were designated as units; on the basis of compositional similarities, rock type and associated lithologies, these were later grouped into collective units (Table 1.3). The lettering sequence within units is based on decreasing lithologic abundance ("a" most abundant), with the exception of units 10 and 11, in which the letters represent inferred stratigraphic position (lowermost = a). Of the 16 units identified for the entire western half of Island Lake, only units 2, 3, 13 and 15 are not (to the author's knowledge) represented in the thesis area. Four of the units are described in detail and interpreted in this chapter, but field mapping emphasized the metasedimentary rocks (Units 4, 5, 10 and 11); all other units (1 and 6-9) are simply described and not interpreted. However, because they occupy prominent positions with respect to the metasedimentary rocks, differentiation of these units in the field is important.

The main constraints on mapping are structural, namely, regional deformation (D_1 , D_2) and late-stage faulting. These mechanisms have obscured many primary sedimentary structures on

outcrop-scale, and introduced complexities to stratigraphic relationships, rendering regional-scale stratigraphy difficult.

For example, in the conglomerates, D_2 strain is seen through locally flattened and slightly elongated (approx. E-W) clasts. The presence or absence of primary imbrication, still visible in many outcrops, is therefore uncertain. The elongation direction approximately parallels the S_2 foliation, which is defined by alignment of muscovite-sericite crystals (thin section observation). According to Fyson (in Herd and Ermanovics, 1976, p. 398), "low-grade metamorphic conditions" persisted throughout D_1 and D_2 , and in general, the rocks in the map area are of greenschist facies. However, lower amphibolite facies metamorphism (post D_2) is exemplified by porphyroblasts of biotite in exposures along the south shore of the east-trending arm of Cochrane Island, and cordierite at the eastern end of Cochrane Bay (Figure 2.1 in back pocket). Cordierite, in particular, commonly masks original sedimentary grading.

Regional-scale effects of F_2 folding and late-stage faulting include a syncline which forms the main east-trending arm of Cochrane Island, and a west-northwest-striking shear zone, which separates the east-trending arm from the southwest projection of Cochrane Island (Figure 2.1 in back pocket). The syncline is flanked by similar lithologies (i.e., 10m,n overlain by 10p) on the north and south sides, but this sequence of feldspathic wacke and siltstone (10m, 10n) overlain by conglomerate (10p, 10q) apparently is restricted to the east-trending arm (syncline) of Cochrane Island. The above mentioned

fault zone, which parallels the southern side of the arm, has obscured original relationships between 10m, 10n and those metasedimentary rocks which lie immediately south of the fault (e.g., 10o, 10r). As a result, the stratigraphy proposed for units adjoining this fault zone (see description of Unit 10) is debatable.

Classification of the metasedimentary rocks is based on that of Williams et al. (1954), but as with any existing sandstone classification, it does not account for metamorphic mineral grains that grew in situ, and therefore cannot be strictly applied. With respect to the conglomerates, an upper size limit of either 2.0 or 4.0 mm has been set for matrix grains, and hence the matrix-size will be documented, using the Wentworth scale, in the individual descriptions. Bed thickness terminology of Ingram (1954) is used throughout the text, and is outlined in Table 2.1. The igneous rocks are classified according to the scheme of Streckeisen (1976). Grain size terminology used for these rocks is as follows: fine-grained (<1 mm), medium-grained (1-5 mm), coarse-grained (>5 mm). Grain size limits of Fisher (1961) have been used for pyroclastic fragments.

Because rocks of the thesis area are metamorphosed to at least greenschist facies, the prefix, 'meta', should be understood to apply to all rocks not so designated herein.

Table 2.1 Classification of stratification based on thickness (after Ingram, 1954).

BEDS	very thick-bedded	100 cm
	thick-bedded	30 cm
	medium-bedded	10 cm
	thin-bedded	3 cm
	very thin-bedded	1 cm
LAMINAE	thick laminae	0.3 cm
	thin laminae	

Relevant Units of the Hayes River Group (Units 1-5)

Unit 1 — Mafic to intermediate metavolcanic and related
intrusive rocks

With regard to the thesis area, lithologies of unit 1 are best exposed on the southeast shore of Linklater Island and on a number of smaller islets between Linklater and Cochrane Islands (Figure 2.1 in back pocket).

The basal unit consists primarily of aphyric (1a) and pillowed flows (1b), both of which are moderately carbonatized, as shown by their reddish-brown colour on the weathered and fresh surfaces. Of the fine-grained (<1 mm) mafic volcanic rocks in the thesis area, most are pillowed (stations 217, 228, 1142 and 1144, Figure 2.2 in back pocket); however, all recognizable pillow forms at these localities are flattened parallel to the schistosity (S_2), and hence stratigraphic top information from pillows is rare.

At station #1142, pillow dimensions range from 30.5 cm (narrowest width) to 1.35 m (greatest length). Here, length: width pillow ratios range from 3:1 to 4:1. Pillowed flows are in places amygdaloidal (1c), with amygdules either close to the selva's inner margin (station #1142) or in layers of massive flows (5-8 cm thick, station #304) adjoining pillowed sequences. Varioles, ranging from 0.4 to 1.2 cm in diameter, occur in pillows at station #1144, but because of extensive pillow flattening, their original distribution is difficult to discern.

Poor exposure and moderate to strong schistosity limits

description of the matrix-supported pyroclastic units, 1e and 1f. Unit 1e (stations 1133 & 1146) has a clast:matrix ratio of approximately 1:5; coarse ash-size fragments (<2 mm) predominate, whereas lapilli-size fragments (up to 1.5 cm) are rare. The volcanic fragments, mostly of intermediate to felsic composition, tend to be aligned with their long axes parallel to the foliation (S_2). Exposures of unit 1f (stations 199 & 1198, Figure 2.2) contain angular lapilli- and bomb-size clasts in a matrix of chloritic schist. Fragments are generally chloritic and felsic, but localized silicification of both matrix and clasts obscures the original composition.

Units 4 and 5 — Wacke-argillite couplets (4a)/Pebble-cobble conglomerate (5a)

Unit 4a - Feldspathic wacke (4-20 cm thick) grading into argillite (0.5 - 20.0 cm thick).

As one of the most abundant rock types in unit 4, unit 4a is exposed on many of the islands immediately south of the Garden Hill Indian Reserve (Figure 2.1 in back pocket). Because thesis work was concentrated on the uppermost beds of 4a (those associated with unit 5a), the chronological position(s) of unit 4a, relative to other sediment-types of unit 4, is not known.

Individual beds of unit 4a typically exhibit normal grading in the basal 1-2 cm of the wacke, then a structureless zone which diffuses into an argillite layer as thick as 20 cm (i.e., AE Bouma divisions). Parallel-laminated zones (B divisions) are rarely observed in the sand-size fraction of these sharp-based beds (station #280, Figure 2.2 in back pocket), as

are synsedimentary isoclinal folds (station #1093). Compared to beds of unit 11b (described later, Plate 2.19), the thickness of wacke-argillite couplets in unit 4a is more variable, mainly because the argillite divisions are commonly thicker (Plate 2.1).

Unit 5a - Pebble-cobble conglomerate, clast-supported;
sedimentary clasts dominant, typically
unstratified

On Dutile Island, northwest of the Garden Hill Indian Reserve (Figure 2.1 in back pocket), the contact between units 4a and 5a is exposed at two locations. On the northwest shore (station #1093, Figure 2.2 in back pocket), wacke-argillite couplets (4a) are transitional into a clast-supported and typically unstratified pebble-cobble conglomerate (5a). On the southeast shore (Plate 2.2), however, the 4a/5a contact is a scoured surface, and because subangular sedimentary rip-ups (resembling Unit 4 lithologies) are present throughout unit 5a, the numerical (4/5) distinction on Figure 2.1 implies erosive channelling synchronous with deposition.

Stratification is typically absent in conglomerate 5a, but where present, it is shown either by a bimodal distribution of clast-sizes (10-20 cm thick beds, Plate 2.3), or by 5-10 cm thick feldspathic wacke interlayers (station #1061, Figure 2.2). Feldspathic wacke is also the composition of the matrix material, which is a fine to medium sand-size sediment (2 mm max.).

Based mainly on a point-count at station #1061, clast sizes range from pebbles to cobbles, with most being in the small cobble-size class (Plate 2.3). Figure 2.3 shows the size distribution of clasts greater than 1.0 cm. The largest clast

Plates

- 2.1 Very thin-bedded siltstone-argillite couplets (no visible small-scale cross-lamination but probably CE Bouma sequences) overlain by wacke bed containing an angular rip-up. Wacke bed is basally graded (A division), but otherwise structureless - no parallel lamination or ripple cross-lamination. Location: islet south of Garden Hill (unit 4a, station #1092, Figure 2.2 in back pocket).
- 2.2 Contact between wacke-argillite couplets (unit 4a) and conglomerate 5a. The clasts are primarily of wacke, siltstone, and argillite composition. Location: southeast shore of Dutile Island (station #1096).
- 2.3 Framework-supported conglomerate (5a) in which stratification shown by bimodal distribution of clast sizes. Clast elongation is attributed to tectonic flattening. Location: mainland within Garden Hill Indian Reserve (station #1061).
- 2.4 Intrusive contact between massive mafic flow rocks (1a, composition of xenoliths) and hornblende tonalite (6a). Location: south shore of Cochrane Bay (station #728).
- 2.5 Arkosic wacke-supported regolith (10a, facies 10-1). Tonalite clasts predominate in the upper part of the photograph (near hammer), whereas numerous fragments of vein quartz are present at the waterline. Location: south shore of Cochrane Bay (station #1021). Length of hammer is 35 cm.

Figure 2.3

Distribution of apparent clast sizes by frequency for a single bed of conglomerate 5a at station #1061 (Figure 2.2 in back pocket). The size data was collected during a 400 point grid-count (see Chapter 4). Clasts measuring less than 1.0 centimetre in apparent long dimension are not shown on the histogram. N = number of measurements, $\bar{x}$ = arithmetic average, and SD = standard deviation.

Q.

recorded in unit 5a at station #1061 is 22 cm,

Conglomerate 5a is framework-supported and has a clast:matrix ratio of about 2:1 (based on point-counting of lithic clast types, see Chapter 4). Clasts are subangular to subrounded; primary imbrication is rare.

Interpretation of Units 4a and 5a

The association of normally graded wacke-argillite couplets (4a) and unstratified pebble-cobble conglomerate (5a), is comparable to greywackes and interbedded argillite conglomerates of the Little Vermilion Formation, Abram Group (Turner, 1972). Turner cited the intraformational nature of argillite conglomerate, and a paucity of soft-sediment deformation structures in the enclosing greywacke and argillite subfacies, to suggest that the conglomerates resulted from erosion (rather than slumping) of previously deposited beds.

Evidence of synsedimentary deformation (e.g., isoclinal folds) in the laterally extensive wacke-argillite beds of unit 4a is also uncommon. Most beds of 4a begin with Bouma division A followed by division E (Plate 2.1); they are interpreted as "classical" proximal turbidites (Walker, 1967, p. 32).

Conglomerate 5a, which overlies beds of unit 4a (Plate 2.2), and contains matrix and clasts which resemble unit 4 lithologies, is interpreted as a mass flow submarine channel-fill deposit. It is conceivable that sedimentary rocks of unit 4 were uplifted by faulting attributed to doming of the Bella Lake

Pluton (6a); and that detritus produced by the erosion of unit 4 strata was incorporated in conglomerate 5a. The small size of clasts (commonly <6 cm) in some outcrops of unit 5a (Plate 2.3 and Figure 2.3), may indicate significant abrasion of the wacke and argillite clasts before resedimentation by turbulent (long-distance) and mass (late-stage) flows.

Stratification within the typically unstratified, framework-supported conglomerate 5a, occurs as interlayers (0.5 - 1.3 m thick) of very thin-bedded siltstone and argillite (4g). Unit 4g is interpreted to represent deposition on and over the levees bordering the conglomerate-filled channels (cf. Nelson and Kulm, 1973).

Early Plutonic Rocks (Units 6-9)

Unit 6 — Tonalite batholiths

Unit 6a - Bella Lake tonalite

The most ubiquitous member of unit 6 within the thesis area is the Bella Lake tonalite (6a), which crops out along the shore of the westward-pointing peninsula south of Cochrane Bay (Figure 2.1 in back pocket).

The tonalite intrudes mafic flow rocks (1a, Plate 2.4) near the northeast corner of the peninsula (station #728, Figure 2.2 in back pocket). Unit 6a is here transitional into a clast-supported, cobble-pebble-boulder conglomerate in which subangular tonalite and mafic metavolcanic clasts predominate (10c).

Farther west, along the south shore of Cochrane Bay, arkosic wacke unit 10b repeatedly grades out of tonalite 6a, and hence defines the base of the Cochrane Bay group (Units 10 and 11).

On the south side of the peninsula, in Garden Hill, the contact between very thin-bedded argillite and siltstone (4g, stations 1057 & 1065) and tonalite (6a) is sharp but slightly sheared, and therefore is not definitely intrusive. At stations 1047 and 1059, tonalite (6a) is flanked by, but does not 'grade' into, feldspathic wacke with siltstone interlayers (10m). Contacts between unit 5a (conglomerate) and unit 10m are not exposed (e.g., stations 1059 & 1060).

In outcrop, the Bella Lake tonalite (6a) is medium- to coarse-grained (4-11 mm) and massive to weakly foliated. Hornblende is the primary mafic mineral; it generally is altered to chlorite and muscovite. As noted by C. R. McGregor (in Weber *et al.*, 1982a, p. 42) "the plagioclase is almost completely altered to epidote giving the tonalite a distinctive green colour on the fresh surfaces".

Unit 7 — Ultramafic rocks, shallow intrusives or flows

Exposures of ultramafic rocks are limited to the small islands between the mid-eastern shore of Linklater Island and the southwest tip of Cochrane Island (Figure 2.1 in back pocket). Outcrops of ultramafic rocks (7a to 7d) are approximately colinear along a northwest strike, and are closely associated with mafic flows (1a, 1b, 1c), ash-bearing tuffs (1e, 1f) and meta-gabbro (8a).

The fine-grained unit 7a, described in detail by Theyer (1977, 1978, 1979, 1980a), is commonly in contact with meta-gabbro (station #1136, Figure 2.2 in back pocket), and although the 7a/8a contacts are consistently sheared, the meta-gabbro is less deformed than either the ultramafic or mafic volcanic rocks. Without well-preserved contacts, however, the inferred age relationships are debatable.

On a small island east of Linklater Island, Theyer (1977, 1978) documented an occurrence of spinifex texture in unit 7a (station #1197), which supports the possibility that "the rock formed from a supercooled ultramafic flow or shallow intrusion" (Theyer, 1978, p. 106).

Unit 8 — Mafic intrusive rocks

Similar to the ultramafic rocks of unit 7, mafic intrusive rocks (8) are best exposed on the islets bordering the mid-eastern shore of Linklater Island. Meta-gabbro (8a) is the predominant lithology, whereas hornblendite (8d) is minor; both are intercalated with the northwest-striking ultramafic rocks.

Unit 9 — Felsic to intermediate metavolcanics and associated porphyries

On a small island, 90 m northeast of the spinifex-bearing ultramafic occurrence (7a, station #1197, Figures 2.1 and 2.2 in back pocket), felsic pyroclastic rocks (9b) are in contact with, and may overlie, actinolite schist (7d, station #1199). Unit 9b,

the dominant lithology at station #1199, was previously interpreted as quartz-pebble conglomerate (Theyer, 1977, 1978).

At the crest of the outcrop in question, unit 9b contains aphyric and feldspar-quartz phyrlic zones. Framework grains typically are of coarse ash-size, with a few areas bearing granules of quartz; the framework is supported by a felsic matrix of fine ash (<0.06 mm). Midway down the steepest side of the outcrop, dendritic fuchsite veinlets (2-5 mm wide) have been introduced. Associated lapilli-size quartz clasts have length: width ratios of 4.0 to 15.0. Here the fragments are rectangular, monomictic and close-set, all of which support auto-brecciation of early (synvolcanic?) quartz veins. However, the lake level exposure, on which Theyer (op. cit.) based his interpretation, is dominated by matrix-supported, subrounded quartz (up to 35 mm) and fuchsite-bearing quartz clasts (up to 10 mm). The clast: matrix ratio approximates 3:1 (visual estimate). The fuchsite fragments, like the quartz, appear to have been derived from veins; possibly they originated from the fuchsite veinlets mentioned above.

In general, felsic to intermediate pyroclastic rocks (9a to 9e) are closely associated with stocks of quartz-feldspar porphyry (9f) and feldspar porphyry (9g). The stocks intrude mafic breccia (1f) and meta-gabbro (8a) along the west to northwest shore of "Dog Island" (stations: 199 & 1196, Figure 2.2).

Medium- to coarse-grained (2-8 mm) quartz-feldspar porphyry (9f) dominates the shoreline exposure on southeast

Linklater Island and northeast "Dog Island". Quartz (dominant) weathers high relative to feldspar, and in most places, the rock displays a weak foliation defined by locally enriched zones of sericite.

Medium-grained (1-2 mm) feldspar porphyry (9g) is more varied and widespread than unit 9f. In Garden Hill, a 2.5 m wide dyke of 9g cuts wacke-argillite couplets (4a, station #1086), whereas immediately west of the reserve, a wider (tens of metres) dyke has intruded 4a (station #279).

Sedimentary Facies of the Cochrane Bay group (Unit 10)

Introduction

In the vicinity of Cochrane Bay, eighteen units or sub-facies (a to r) have been recognized in strata representing the second episode of sedimentation (i.e., Unit 10). The term unit ("u") is used here to link exposures which have both macroscopic compositional similarities and identical sedimentary structures. Based on association and proposed environment of deposition, these units have been grouped into four major facies, namely 10-1 to 10-4.

As used herein, the term unit does not imply confinement to a single time interval. Thus, units may occur once or more than once within a given facies. The four facies (labelled 10-1, 10-2,...) are inferred to contain progressively younger lithologies, even though the lettering sequence for units within each facies (units 10a, 10b, 10c) does not necessarily follow

this pattern. Therefore, a distinction that is made between regional facies and local facies refers strictly to 'lateral' recurrence or non-recurrence, considering that each facies (i.e., an associated group of units) is thought to occur only once in the 'vertical' succession.

Facies 10-1 Ungraded, arkosic wacke-dominated fragmental rocks

This regional facies is generally tens of metres thick, and is best exposed along the south shore of Cochrane Bay, the southwest shore of Cochrane Island, and on the west side of Pitch Pipe Island (Figure 2.4). It is subdivided into five sub-facies or units "a" through "e" of map unit 10 (Figure 2.1 in back pocket), based on the relative proportion and character of arkosic wacke matrix to framework.

Unit 10a - Arkosic wacke-supported regolith

At two localities on the south shore of Cochrane Bay (stations 623 & 1021, Figure 2.4), tonalite (6a) of the Bella Lake Pluton is transitional (6-8 m distance) into a rust-coloured arkosic wacke, which culminates as the supporting matrix for an unstratified rubble breccia (Plate 2.5). In the matrix, very coarse sand to granule-size quartz grains (4 mm max.) exhibit limited rounding, whereas the framework constituents of leucocratic vein quartz cobbles and tonalite boulders (up to 90 cm) are angular. The regolith occurs in isolated pockets, having neither vertical nor lateral expanse in excess of 2-3 m.

Distinct from the above is a finer-grained version, which

Figure 2,4

Facies distribution map for
Cochrane Bay group. Station
referenced in the text.

Facies 10-1. Ungr
wacke-dominated fr
(units 10a to 10e)

Facies 10-2. Well
feldspathic wackes
(units 10f to 10n)

Facies 10-3. Ungr
wacke-supported co
(unit 10o).

Facies 10-4. Inve
ungraded framework
conglomerates (uni

t 10 of the
mbers are

d, arkosic
ental rocks

ratified
d siltstones

d, arkosic
omerate

ly graded →
minated
10p to 10r).

94°48'
53°58'

53°51'
94°32'

at station #1010, has been termed "paleosaprolite" (cf. Bates and Jackson, 1980, p. 556). The arkosic wacke matrix contains angular, tonalite-derived "granule and pebble-size" clasts (up to 4.5 cm); they compose more than 25% of the exposed face. Clast percentage is sufficient to classify as a "conglomerate", but because the fragments are monomictic, close-set and frequently in contact, this exposure is more readily classified ~~as an~~ in situ breccia rather than a granule-pebble conglomerate.

Unit 10b - Arkosic wacke, typically unstratified

Unlike the rarely exposed rubble breccia (10a), the tonalite (6a) is repeatedly fringed by coarse sand to granule-grade arkosic wacke (10b). In general, this arkosic wacke is not pervasively stained like that associated with unit 10a; it grades out of the tonalite within a few centimetres, and close examination is required to distinguish it from the plutonic rock. The quartz, feldspar and hornblende crystals of the medium- to coarse-grained tonalite maintain a homogeneous granitoid texture, whereas in the sediment, quartz grains weather "high"; feldspar, "intermediate to low"; and hornblende, "low to absent".

Unit 10b is typically devoid of clasts and stratification, but an exception to this rule occurs at station #132 (Figure 2.4). The matrix-supported clasts are strictly pebble-size (up to 4 cm), mainly because the matrix is sufficiently coarse to include granule-grade material (4 mm max.). The clast: matrix ratio is approximately 1:3, and the clast types, in decreasing abundance (visual estimates), are:

- i) argillite rip-ups
- ii) blue-grey quartz
- iii) yellow-brown chert
- iv) fuchsite

Stratification is commonly defined by thick brown to black argillaceous laminae (0.4 - 1.0 cm). These laminae lack internal grading, and the lower and upper boundaries appear to diffuse into the matrix. In a few places, laminae composed of matrix grains are normally graded, with facing directions consistently to the northeast.

Unit 10c - Unstratified cobble-pebble-boulder conglomerate, locally clast-supported; subangular tonalite and mafic meta-volcanic clasts predominate

This unit is not described in detail here because it is limited to a single exposure; unit 10c appears on Man. Min. Res. Div. Map 1982 I-2 as unit 101.

Unit 10d - Chloritic arkosic - feldspathic green ~~wacke~~; contains granule and pebble-size fragments

In the middle of the south shore of Cochrane Bay, (station #1149, Figure 2.4), medium-grained chlorite-rich arkosic wacke immediately overlies arkosic wacke of unit 10b. In this instance, clasts are absent from 10d. Stratification takes the form of a few thin laminae (<3.0 mm) compositionally similar to the matrix, which are spaced several centimetres apart over the entire exposure (80-90 cm true thickness across bedding).

Granules and pebbles are sporadically distributed in the outcrops of 10d that are exposed on the small islets between Linklater and Cochrane Islands (e.g., station #263), and on the

southwest shore of Cochrane Island (e.g., stations 134 & 137). The unstratified exposures are entirely matrix-supported (sand-size) and have a clast:matrix ratio of about 1:2. Clasts are subangular to subrounded and, on the basis of visual estimates, the predominant types are:

- i) tonalite - granodiorite, medium-grained, massive
- ii) quartz-feldspar porphyry, medium-grained
- iii) feldspar porphyry, fine- to medium-grained
- iv) mafic volcanic, fine-grained

Unit 10e - Cobble-boulder conglomerate, commonly clast-supported; abundant well-rounded tonalite and subrounded amphibolite clasts; minor (<10%) bedded and trough cross-bedded wacke

At the aforementioned station #1149, conglomerate of unit 10e is laterally equivalent to chloritic arkosic wacke (10d). However, a transitional matrix-supported zone more than 3 m thick, forms the base of unit 10e (and represents the clast-bearing fraction of 10d). In general, unit 10e comprises 8-10 m thick beds of framework-supported and unstratified conglomerate (Plate 2.6). Where present, the wacke beds are either sharp-based and graded (0.09 - 0.80 m thick, Plate 2.7), or crossbedded (medium- to large-scale sets, 7-40 cm thick) in 2-3 m thick cosets (Plate 2.8).

At station #1032, a coarse-grained feldspathic wacke interbed (78.5 cm thick) is distinctly separate from the conglomerate beds above and below. The bottom is marked by low-amplitude scours (3.5 cm thick); thick, granule-bearing laminae (0.4 - 1.0 cm) near the base of the wacke exhibit normal internal grading, as do the increasingly more diffuse laminae in the upper part of this bed. In the enclosing conglomerate, arkosic wacke

Plates

- 2.6 Unstratified conglomerate 10e. Light-coloured clasts are tonalitic, whereas the darker, recessive-weathering clasts are amphibolites and mafic volcanics. Location: south shore of Cochrane Bay (station #1023, Figure 2.4). Length of hammer is 35 cm.
- 2.7 Undulatory contact between conglomerate and feldspathic wacke interbed (10e, facies 10-2). Granule-bearing laminae in the wacke bed show normal internal grading. Stratigraphic top towards top of photograph. Location: south shore of Cochrane Bay (station #1032). Length of card is 8.5 cm.
- 2.8 Trough cross-stratified arkosic wacke bed in the uppermost section of unit 10e (facies 10-1). Location: south shore of Cochrane Bay (station #1151). Length of knife is 9 cm.
- 2.9 Planar to gently curved pebble-granule layers within feldspathic wacke (10f, facies 10-2). Top direction is towards top of photograph. Location: southernmost tip of Cochrane Island (station #26). Diameter of lens cap is 5 cm.
- 2.10 Diffuse contacts (both lower and upper) between typically unstratified feldspathic wacke (10g) and a layer of carbonate clasts (10hl, facies 10-2). Stratigraphic top towards top of photo. Location: small island bordering the most southerly entrance to Cochrane Bay (station #17).

Figure 2.5 Distribution of apparent clast sizes by frequency for a single bed of conglomerate 10e (facies 10-1) at station #1032 (Figure 2.4). The size data was collected during a 400 point grid-count (see Chapter 4). Clasts measuring less than 1.0 centimetre in apparent long dimension are not shown on the histogram. N = number of measurements, $\bar{x}$ = arithmetic average, and SD = standard deviation.

matrix consists of very coarse sand to granule-size grains (4 mm max.), significantly coarser than the feldspathic wacke interbed. The clasts are not imbricated, and range in size from pebbles to boulders, with most being in the medium cobble-size class (Plate 2.7). Figure 2.5 shows the size distribution of clasts greater than 1.0 cm. The largest clast recorded in unit 10e at station #1032 is 38 cm.

Point-counts at #1032 indicate a clast:matrix ratio of about 3:2. On the basis of visual estimates during counting, the clasts are subrounded (amphibolite) to rounded (tonalite). (See Chapter 4 for detailed clast compositions).

General Interpretation of Arkosic Wacke-dominated

Fragmental Rocks (facies 10-1)

The five sub-facies or units ("a" through "e") are grouped genetically because of their close stratigraphic association (maximum exposed thickness of 12-15 m), and because they are inferred to be the product of a single depositional environment. Local differences in environmental conditions were responsible for development of the five units.

Based primarily on the points listed below, facies 10-1 is interpreted as the product of deposition in an alluvial mid-fan environment:

- (1) Regolithic units 10a and 10b, at the exposed "base" of unit 10, rest unconformably on tonalite (6a) and contain abundant clasts (0.4 - 90.0 cm) of this tonalite. Turner and Walker

(1973, p. 837) argued that this type of basal contact is "typical of alluvial fan deposits, unknown in deep basin conglomerates, and uncommon in fluvial conglomerates."

(2) A low ratio of coarse-grained "mass flow":coarse-grained fluid flow deposits, together with a low ratio of coarse-grained:fine-grained "mass flow" deposits (see p. 57), concurs with deposition at some distance (mid-fan) from the apex.

(3) The conglomeratic beds (10c, 10e) tend to be thick, massive, and lack both imbrication and cross-stratification; cross-stratification in facies 10-1 is restricted to the uppermost wacke interbeds of unit 10e (Plate 2.8). This suggests that continuous current activity, typical of a braided river environment, was not operative during the period of major deposition.

(4) Grading (normal or inverse) was not observed in facies 10-1 conglomerates, whereas graded bedding is commonly present in Archean deep-water conglomerates (Walker and Pettijohn, 1971; Teal and Walker, 1977; Wood, 1980).

In addition, beach and glacial environments are rejected as possible depositional sites for facies 10-1, following the detailed arguments of Turner and Walker (1973, p. 837-838) for what they interpreted to be alluvial fan deposits of the Archean Ament Bay Formation. Although the Ament Bay differs in detail from facies 10-1, the reasons of Turner and Walker for ruling out beach and glacial environments are applicable to facies 10-1.

The complete alluvial fan system, as exposed along the south shore of Cochrane Bay, consists of both facies 10-1 and

facies 10-2 (see p. 62), and although paleoflow information is virtually absent, facies characteristics such as clast-size, bedding thickness, and sedimentary structures suggest ~~that~~ depth of flow, confinement of flow, and slope of the fan surface decreased from south to north, or from mid (facies 10-1) to distal (facies 10-2) parts of the fan system.

The alluvial fan proposed herein is comparable to the Kosi River fan of India, a humid-region fan that is being constructed entirely by fluvial processes (Gole and Chitale, 1966). In both cases, there is little evidence of true "debris flow" deposits (unit 10d; Johnson, 1965; 1970, chp. 14) or sieve deposits (Hooke, 1967; Bull, 1972), characteristic of arid-region alluvial fans. However, clay-deficient "mass flow" deposits (units 10a, 10b) occur throughout facies 10-1, and hence the proposed fan was not generated solely by fluvial (fluid flow) processes.

Detailed Interpretation of Facies 10-1 (units 10a to 10e)

For the regolith component of unit 10a (Plate 2.5), poor sorting of the matrix-supported breccia, lack of both grading and stratification, and the complete absence of individual beds, all are suggestive of a "debris flow" origin (Hooke, 1967; Bull, 1972; Walker, 1975a). However, these features are here attributed to in situ weathering because of the limited compositional range of the clasts (i.e., vein quartz and tonalite), the close-set nature of the clasts, and the proximity

of unit 10a to the inferred source rock (unit 6a). The presence of displaced vein quartz fragments suggests 'some' mass transport; possibly solifluction.

Debris flow (or mud flow) deposits in the classic sense (e.g., those derived from high density, high viscosity flows rich in clay- to silt-size detritus) have not been identified in the Late Metasedimentary Rocks (Cochrane Bay group); sufficiently large volumes of fines probably were not available in the source area to initiate mud flows. Because the arenaceous matrix of unit 10b argues against a true debris flow origin; the less specific term "mass flow" is preferred for this fragment-bearing arkosic wacke, since it contains no direct evidence for a viscous, matrix-strength support system during transport. In particular, the high matrix (1-4 mm) content of the arkosic wacke combined with low quantities of clay-grade sediment (see Table 3.1), imply deposition from grain dispersion rather than as a result of viscous flow (cf. Middleton and Hampton, 1973).

With regard to coarse-grained versus fine-grained mass flow deposits, arkosic wacke (10b), which overlies tonalite (6a), is a significantly finer-grained and more widespread regolith than 10a or 10c (Figure 2.1 in back pocket). This lateral (not vertical) juxtaposition of boulder-bearing (minor) and granule-grade (extensive) regolith, illustrates a low ratio of coarse-grained: fine-grained mass flow deposits in facies 10-1: this point substantiates the likelihood of a mid-fan environment, wherein detritus entrained by mass flows was primarily of sand- and granule-size.

In both units 10b and 10d, the general absence of sedimentary structures suggests the lack of a tractional phase during deposition, and therefore sand-granule mass flow, enhanced by an absence of vegetation, is a plausible mode of origin. The two units are, however, believed to differ with respect to grain-support mechanism.

For example, arkosic wacke (10b) has a clay-deficient matrix and hence, dispersive pressure is a probable grain-support mechanism for this unit (see p. 57). In addition to the massive and ungraded nature of unit 10b, two features resemble those of grain flow deposits (Stauffer, 1967, p. 491): diffuse parallel lamination (sorting attributed to kinetic sieving?) and sporadic clasts floating in a sandy matrix. Stauffer suggested that grain flows are further characterized by the absence of traction-current features, such as cross-lamination, ripple marks, and current scours, none of which were observed in unit 10b. Although 10b cannot be positively identified as a grain flow deposit, Middleton and Hampton (1973) stressed that, in the absence of excess pore pressures, relatively steep slopes (18-37°) are required for true grain flow. The present author suggests that steep slopes (possibly abetted by in situ spheroidal weathering) may explain well-rounded tonalite clasts (10e, facies 10-1), in juxtaposition with the source terrane (e.g., Bella Lake Pluton).

Feldspathic green wacke (10d) has a higher clay mineral content (15% from thin section) than unit 10b, so that clay-water

suspensions could have provided the major support for solid grains during flow (cf. Pettijohn et al., 1972, p. 330). In addition, unit 10d, which is rarely stratified and commonly clast-bearing, is interpreted as a true debris flow deposit, because support of grains by cohesion of the fluid phase distinguishes debris flow from grain flow (dispersive pressure) and turbidity-current flow (turbulence).

For conglomerate of unit 10e (Plate 2.6), the combination of framework-support and extreme disparity of clast size with widespread absence of stratification, is taken to indicate deposition by sudden floods in streams of considerable magnitude. Although the polymodal nature of the conglomerate suggests that grain size selection processes were not important during transport (mass flow), the framework support is probably due to the rolling and accumulation of clasts along a bed (fluid flow). The cosets of trough cross-bedded wacke in the uppermost part of 10e (Plate 2.8), distinguish 10e from framework-supported conglomerates associated with turbidites; interpreted as deposition from clast dispersion above the bed (Walker, 1975a) or from debris flows, with no bedload rolling (Cook et al., 1972; Hampton, 1972).

The massive cobble-boulder beds of unit 10e (lower part of unit) are attributed to deposition during flood surges; possibly where flow was confined (e.g., canyons), because unconfined fluid flow across a typical alluvial fan surface would not have the competence to transport boulders and cobbles for any great distance (McGowen and Groat, 1971). Conglomeratic beds

(10e) are comparable to the massive gravel deposits, up to several metres thick, formed during the 1964 flooding of the Rubicon River, California (Scott and Gravlee, 1968). These Rubicon deposits had steep fronts transverse to the channel trend, and movement of detritus along the channel floor probably was by way of large gravel waves. Partial blocking of major channels by deposition high on an alluvial fan surface conceivably could result in damming of flood waters; breakage of the dam would result in a surge of water, sand, and large clasts that would sweep down the channel and spread out, depositing a thick bed of unstratified cobbles and boulders, with a sand-granule matrix, over the fan surface (10e).

Also important in the interpretation of conglomerate 10e, is the rounded to well-rounded nature of the clasts. One explanation for the high degree of rounding, mentioned in the depositional analysis of unit 10b, is a steep-sloped fan or channel surface (see p. 58). A second explanation can be offered based on the absence of terrestrial vegetation at the time the proposed alluvial fan system was deposited. Specifically, without vegetation cover there is little resistance to run-off, lag between precipitation and run-off is extremely short, and peak discharge duration is short (Schumm, 1968, p. 1577). In addition, the streams were characterized by a high bedload/suspension load ratio, because of a paucity of clay-size material. The combination of high bedload/suspension load ratio, short lag between precipitation and run-off, and short duration peak discharge, implies that rounding of clasts (>2 mm) "might

have proceeded at a more rapid rate than at present" (McGowen and Groat, 1971, p. 37). The rounding of clasts in unit 10e (and in the entire alluvial fan system) may thus be a first-cycle feature.

Interpretation of wacke-enriched beds within unit 10e is as follows:

(1) The sharp-based, coarse-grained wacke bed shown in Plate 2.7, probably truncated the underlying conglomerate during waning flood stage, when water depth was low and velocity able to transport only detritus of sand- and granule-size (bar top deposition?). Because grain size precluded development of ripples, parallel laminae are the sole stratification type in the wacke bed (Williams, 1967, 1970).

(2) In the uppermost exposures of unit 10e, grouped sets of trough cross-bedded arkosic wacke, with 20 cm mean trough thickness (Plate 2.8), are believed to have formed by migration of sinuous crested dunes (Harms et al., 1975, p. 24, 47-49), possibly in braided stream channels. This implies that depth and velocity of the flow are significantly above those appropriate for lower flat bed formation (see above). Based on the humid-fan model of McGowen and Groat (1971, Figure 31), and the position of the trough cross-strata [near the top of the "arkosic wacke-dominated fragmental rocks (facies 10-1)", and below the "well-stratified feldspathic wackes and siltstones (facies 10-2)"], the author believes that these cross-strata represent a mid- to lower fan transition. However, planar tabular cross-stratification, commonly associated with such a transition (Bluck, 1965; Smith,

1974) and indicative of transverse or cross-channel bar deposition (Smith, 1970, 1971; Cant and Walker, 1978), was not observed here.

Facies 10-2 Well-stratified feldspathic wackes and siltstones

Within the thesis area, this regional facies is best exposed along the perimeter of the east-trending arm of, and at the southernmost tip of, Cochrane Island. At the latter exposure, facies 10-2 attains a maximum thickness of 100 m (unit 10f, stations 25 & 44, Figure 2.4).

Facies 10-2 consists of nine units (10f through 10n) seven of which are exposed in the thesis area, and hence described herein (Figure 2.1 in back pocket). Units 10f (stations 11 & 25) and 10g (stations 2 & 1043) are associated with, and probably overlie, sandstone units 10b and 10d of facies 10-1. These units may, however, be intercalated, because facing directions are not always determinable.

Unit 10f - Feldspathic wacke, localized layering of predominantly felsic pebbles and granules

On the southernmost tip of Cochrane Island (station #132, Figure 2.4), unit 10b (facies 10-1) is intercalated with the clast-bearing fraction of 10d (facies 10-1, stations 133 & 134), which together are overlain by a 90 m thickness of small- to medium-scale, trough cross-laminated medium-grained, feldspathic wacke (10f, stations 25, 26 and 44, Figure 2.6).

At station #25, relief of the troughs rarely exceeds 4-5

contact of this scour are distinctly asymmetric). These northwest-trending (314°) asymmetrical depressions (10-15 cm deep) are basally-infilled by framework-supported pebbles (0.5 - 1.5 cm), which in the body of the main scour, fine upward into matrix-supported (2 mm max.) pebbles and granules. Based on the asymmetry, paleoflow apparently was either northwest or southeast, but the present 75° northerly dip limits further interpretation.

Unit 101 - Granule-bearing feldspathic wacke (0.1 to 1.5 m thick beds) interlayered with argillite (2-20 cm thick)

This unit is not described in detail here because it is not exposed in the thesis area; unit 101 appears on Man. Min. Res. Div. Map 1982 I-2 as unit 10g. See below for brief description.

Unit 10m - Feldspathic green wacke (5-15 cm thick) with siltstone, argillite and sporadic calcareous interlayers (1-3 cm thick), locally showing normal grading at base of wacke

Unit 10m, together with 10n and 10l (rare), crop out along the perimeter of the east-trending arm of Cochrane Island. These units consistently (and conformably) underlie conglomerate 10p (facies 10-4), which dominates the inland part of the arm. The above mentioned unit 10l, exposed only at the eastern tip of the island, is distinguished from 10m by:

- 1) concentrations of very coarse sand to granule-grade material at the bases of medium- to coarse-grained, ungraded wacke beds

cm. Thin laminae (1-4 mm) define the lower contacts of asymptotic, low-angle foresets; these lower bounding surfaces are smooth and planar to gently curved. Pebble-granule layers tend to be parallel to, rather than marking the basal surfaces of, the troughs (Plate 2.9). In most places these layers consist of a single row of pebbles, but some are several pebbles thick. The clasts generally are touching, but some layers consist of pebbles scattered on, or in isolated clusters along, bedding. Few layers are continuous across the width of an outcrop; most fade out laterally within a couple of metres.

Most pebble-granule layers lack preferred fabric, and none of the layers exhibit graded bedding. Some clasts are aligned along a common base, providing a basis for determining facing directions where trough cross-laminae are not well developed.

The clast types are, in order of decreasing abundance (based on visual estimates only):

- i) quartz-feldspar porphyry, massive, medium-grained
- ii) saccharoidal quartz, fine-grained
- iii) argillite
- iv) fuchsite-bearing quartzite

Clasts are commonly subrounded to rounded; most argillite pebbles are distinctly lenticular.

Unit 10g - Feldspathic wacke, sporadically distributed felsic pebbles and rare cobbles

On the mainland (station #2, Figure 2.4) and small islands (stations 14, 16 and 17) bordering the most southerly entrance to Cochrane Bay, medium- to coarse-grained feldspathic wacke containing felsic volcanic clasts (10g) is in close

association with arkosic wacke (10b, facies 10-1, stations 12 & 13). The stratigraphic relationship between these two units is unclear, because facing indicators in the arkosic wacke (10b) are absent and a lake channel interrupts the sequence. Evidence for at least some structural complications along this channel is a 3 m "thick" slice of sheared argillite (11c) at station #11 (Figure 2.1 in back pocket). Facing indicators in the feldspathic wacke (10g), however, point consistently to the southwest.

In addition, at adjacent stations 6 and 15, where sediments of the Hayes River Group (4a) are separated from those of the Cochrane Bay group (10g) by 8 metres of broken stratigraphic sequence, both units strike, dip and face in the same directions. Unit 10g is stratigraphically above 4a, and both units appear to have been folded at the same time and by the same mechanism. This observation is comparable to those of Fyson (in Herd and Ermanovics, 1976; see "Structural Geology"), from which he concluded that the Cochrane Bay group (Units 10 and 11) is "affected by the same succession of polyphase structures as affect the underlying volcanics and greywackes" (Units 1-4; Fyson et al., 1978, p.1819).

- Unit 10h - Carbonate (0.5 - 1.0 m thick beds) interbedded with unit 10g (0.4 - 0.6 m thick)
- 10h1 - Intraformational cobble-boulder conglomerate

On the same islands mentioned for unit 10g, are 12-20 m thick sections (station #17) in which carbonate (10h) is interbedded with feldspathic wacke (10g). Where interbedded with 10h, unit 10g is typically void of clasts, with the exception of

a 0.8 m thick bed which underlies the carbonate at station #17.

At the northwest end of #17, stratigraphically above unit 10h, subunit 10hl occurs as an isolated layer (Plate 2.10) within an otherwise unstratified, pebble-bearing wacke (10g).

Unit 10i - Feldspathic wacke (feldspar-rich), locally cross-laminated (3-8 cm thick sets)

Unit 10j - Argillaceous wacke with quartz granule framework, typically cross-stratified (20-40 cm thick sets)

Units 10i and 10j are not described in detail here because they are not exposed in the thesis area; they appear on Man. Min. Res. Div. Map 1982 I-2 as units 10c and 10e respectively.

Unit 10k - Feldspathic wacke containing sporadic scours (up to 7 m wide) basally-infilled by pebbles

This lithology (10k) is most prevalent on the northeast-trending islets near the eastern tip of Cochrane Island (stations 410-414, 427-431, Figure 2.4). Because unit 10k does not appear on Cochrane Island, its stratigraphic position with respect to strata at the east end of Cochrane Island is unclear. However, because it is interstratified with wackes and siltstones at the eastern end of Cochrane Bay, unit 10k is considered to be part of the 'lower' sandstone facies (10-2).

In general, pebble-bearing scours, contained within otherwise unstratified medium- to coarse-grained feldspathic wacke, are sporadically distributed. The basal surfaces are planar to gently curved, and the dimensions of scours rarely exceed 2 m wide by 0.25 m thick. An exception is station #410, where a scour measures 6.75 m by 0.6 m (parts of the lower

contact of this scour are distinctly asymmetric). These northwest-trending (314°) asymmetrical depressions (10-15 cm deep) are basally-infilled by framework-supported pebbles (0.5 - 1.5 cm), which in the body of the main scour, fine upward into matrix-supported (2 mm max.) pebbles and granules. Based on the asymmetry, paleoflow apparently was either northwest or southeast, but the present 75° northerly dip limits further interpretation.

Unit 101 - Granule-bearing feldspathic wacke (0.1 to 1.5 m thick beds) interlayered with argillite (2-20 cm thick)

This unit is not described in detail here because it is not exposed in the thesis area; unit 101 appears on Man. Min. Res. Div. Map 1982 I-2 as unit 10g. See below for brief description.

Unit 10m - Feldspathic green wacke (5-15 cm thick) with siltstone, argillite and sporadic calcareous interlayers (1-3 cm thick), locally showing normal grading at base of wacke

Unit 10m, together with 10n and 10l (rare), crop out along the perimeter of the east-trending arm of Cochrane Island. These units consistently (and conformably) underlie conglomerate 10p (facies 10-4), which dominates the inland part of the arm. The above mentioned unit 10l, exposed only at the eastern tip of the island, is distinguished from 10m by:

- 1) concentrations of very coarse sand to granule-grade material at the bases of medium- to coarse-grained, ungraded wacke beds

ii) argillite divisions which are substantially thicker
and less rhythmic than those of 10m and

iii) paucity of calc-silicate interlayers

Normal grading in the medium-grained feldspathic wacke (10m) is atypical (unlike 11b), but where present, basal grains are not significantly coarser than the upper framework grains (unlike 101). The wacke division is sharp-based and may contain oblong calc-silicate nodules, which tend to be aligned in certain beds (Plate 2.11). Continuous calc-silicate layers may appear in lieu of the wacke. The lower division (i.e., wacke or calc-silicate) grades into siltstone, and then argillite in the uppermost part of the bed. Small-scale cross-lamination was not observed in the siltstone, and the siltstone-argillite divisions tend to undulate: these two points distinguish 10m from the classical turbidites of 11b.

Unit 10n - Siltstone (0.2 - 20.0 cm thick) with argillite
and sporadic calcareous interlayers (0.1 -
10.0 cm thick) (formerly 101)

As previously mentioned (p. 68), unit 10n is most prevalent along the north and south boundaries of the east-trending arm of Cochrane Island. In general, 10n is characterized by wavy (but parallel) silt/clay couplets in which silt-layer thickness is approximately equal to clay-layer thickness (stations 80 & 93, Figure 2.4; Plate 2.12). In a few places, however, the silt layers are thicker than the clay layers (station #99, Plate 2.13). The two have not been mapped as subunits, because pervasive lichen cover precludes consistent differentiation.

Plates

- 2.11 Planar beds of feldspathic wacke with siltstone-argillite interlayers (10m, facies 10-2). Calc-silicate nodules are restricted to the basal part of the thickest wacke bed; the asymmetry of these nodules is probably controlled by soft-sediment deformation. Location: north shore of Cochrane Island (station #111, Figure 2.4).
- 2.12 Couplets of siltstone grading into argillite (10n, facies 10-2), in which silt- and clay-layer thicknesses are approximately equal. Note synsedimentary folding and faulting. Stratigraphic top towards base of photograph. Location: south shore of the east-trending arm of Cochrane Island (station #93).
- 2.13 Couplets of siltstone grading into argillite (10n, facies 10-2), in which the silt layers are commonly thicker than clay layers. Small-scale cross-lamination is visible in some silt layers. Top direction is towards top of photograph. Location: eastern tip of Cochrane Island (station #99).
- 2.14 Unstratified arkosic wacke-supported conglomerate (10o, facies 10-3). The oblong boulder in the uppermost part of the photograph (and the diffuse one in the lower right corner) are biotite-bearing feldspar porphyry (subunit 6f1). Location: east side of the south-west-trending extension of Cochrane Island (station #55).
- 2.15 Feldspathic wacke truncated by an inversely graded and framework-supported bed of conglomerate (10pl, facies 10-4). Location: south shore of the east-trending arm of Cochrane Island (station #73).

Where silt and clay occur in equal abundance, each couplet becomes darker from bottom to top. Polished slabs show that most clay/silt contacts are sharp, whereas the silt/clay contacts more commonly are gradational or diffuse (station #93, Plate 2.12). Individual layer thicknesses (i.e., silt, calc-silicate and clay) at station #93 have an approximate range of 0.5 - 3.0 mm (thin laminae). Calc-silicate layers, where present, substitute for the silt layer. A lichen-free outcrop at station #93 allows observation of synsedimentary loading into clay layers, and small-scale nappes with westward-facing downslope slumping. Right-lateral faults with offsets of 2-3 mm lie perpendicular to strike.

Where silt layers are thicker than the clay layers, the couplets are typically thicker (silt: 3-10 cm; clay: 0.5 - 2.5 cm) than in the previously discussed couplets, and the transitional grey-coloured areas between light silt and dark clay are more readily visible (station #99, Plate 2.13). Basal concentrations of fine sand-size grains and small-scale cross-lamination locally occur in the sharp-based silt or calc-silicate layers. Parallel lamination sporadically occurs in the grey-coloured zones, whereas the uppermost clay layers are consistently massive. The preceding observations (3) are interpreted as CDE Bouma divisions, however, the sequence is truncated or interrupted in many beds (i.e., less rhythmic than the sequences in units 4g and 11c). Synsedimentary deformation in the clay layer has produced load structures and pseudonodules up to 2 cm in maximum dimension.

8

Interpretation of Well-stratified Feldspathic

Wackes and Siltstones (facies 10-2)

All units of facies 10-2 (10f through 10n) are believed to be either a direct or indirect result of sheetflood processes on the lower fan. Sheetfloods, which are flood flows of 'low viscosity', spread out onto the fan surface at the downstream ends of channels. According to Rahn (1967, p. 603), they generally develop into short-lived upper flow regime conditions where depth of flow is very shallow (8-30 cm). Sheet flows originate in and disperse out of a main stream channel, whereas the ensuing deposition occurs rapidly in shallow ephemeral distributary channels. Beds in the channels can be cross-stratified, laminated, or massive (Bull, 1972, p. 66), depending on the rate of deposition.

Medium-grained feldspathic wacke (10f), which contains small- to medium-scale cross-stratification (as do units 10i and 10j), was probably deposited by sheetfloods in which slow fluid flow deposition allowed time for sedimentary structures to form. The pebble- and granule-bearing nature of unit 10f indicates that some larger clasts were carried by the sheet flows, and the pebble layers within the feldspathic wacke may represent lags of coarse detritus laid down as the flow began to wane. This interpretation is supported by the fact that most pebble-granule layers are discontinuous, implying coarse deposition only in the lower parts of shallow transitory channels.

Scours contained within otherwise unstratified medium- to coarse-grained feldspathic wacke (10k), are basally-infilled by pebbles, marking channels up to 6.75 m wide by 0.6 m thick. Unlike unit 10f, the feldspathic wacke in 10k is typically massive, implying that the sheet flows were heavily laden with sand-size detritus, and that this sediment was rapidly deposited. Interpretation of the gently curved, pebble-bearing scours is on a slightly larger scale, but is comparable to the proposed explanation for pebble-granule layers within unit 10f.

Medium-scale beds of feldspathic green wacke that grade into siltstone-argillite (unit 10m, Plate 2.11) are parallel sided and laterally extensive (they crop out along the perimeter of the east-trending arm of Cochrane Island). These beds are attributed to deposition from decelerating (distal) sheet floods (cf. Collinson, 1978). Unit 10m is comparable to "horizontally stratified sandstone (Sh)", present in stream flow deposits of the Lower Member of the Mississippian Cannes de Roche Formation (Rust, 1978a,b). Beds of 10m contrast with sharp-sided sandstone beds of Allen (1964) and Leeder (1974) which are 'limited' in lateral extent, and hence are interpreted as crevasse splay deposits (i.e., deposition incurred by flood-water breaching of the main channel levees).

Closely associated with unit 10m, especially along the perimeter of Cochrane Island, is unit 10n, which consists of grey-coloured, very thin- to medium-size siltstone-argillite couplets (Plates 2.12 and 2.13). These couplets are interpreted

to represent deposition on levees and interchannel areas of a lower alluvial fan (cf. Allen, 1964). Specifically, fluid (sheet) flow over the levee was probably oblique to the channel axis and hence was rather weak, which resulted in deposition of thin Bouma CDE, CE and DE sequences. The presence of sediment-infilled desiccation cracks in "float blocks" of unit 10n, together with outcrops in which units 10m and 10n are interstratified, supports the above interpretation of 10n.

Because unit 10h (carbonate interbedded with feldspathic wacke) is apparently restricted to two small islands (stations 15 & 17, Figure 2.4; Plate 2.10) bordering the most southerly entrance to Cochrane Bay, its stratigraphic position (part of facies 10-2?) and interpretation, relative to other units of the Cochrane Bay group, is uncertain. Placement of unit 10h into facies 10-2 is based primarily on its interstratification with feldspathic wacke unit 10g. Interbedded carbonate and detrital silicate may represent the onset of a marine transgression, which allowed carbonate material to infiltrate the 'lower alluvial fan', and hence transform it into a supratidal zone. This concept is similar to that illustrated by the Permian cyclic strata of the Northern Midland and Delaware basins (Silver and Todd, 1969). Also, unit 10h is comparable to a "transitional zone" in the uppermost part of the Carboniferous Mission Canyon Formation (Houlik, 1973, p. 502-3).

Facies 10-3 Ungraded, arkosic wacke-supported conglomerate

This local facies consists of only one unit, 10o, which attains a thickness of at least 25 m (station #60, Figure 2.4). As mentioned in "Background" to Chapter two (p. 29), 10o is the oldest of two units (10o, 10r) which appear only on the south side of the fault zone on Cochrane Island (Figure 2.1 in back pocket). The relationship of units 10o and 10r to 10p and 10q has been obscured by this fault. Laminated siltstone-argillite (10n, facies 10-2) is the most credible link, because it apparently underlies all of 10o, 10p and 10q. With regard to 10o, the author suspects that 10n has been significantly eroded, because of the preponderance of angular 10o clasts which resemble 10n (6.3% from point-count). A thickness of about 2 m of unit 10n recurs above conglomerate 10o (below 10r), but because 10n does not reappear within or above 10p, 10q or 10r, unit 10o is inferred to mark the base of a second conglomeratic sequence which, like facies 10-1 — 10-2, is initially arkosic (10o, facies 10-3) becoming feldspathic higher in the section (10p, 10q, 10r, facies 10-4).

Unit 10o - Cobble-pebble-boulder conglomerate, matrix-supported; polymictic, subangular sedimentary clasts dominant; rare argillaceous laminae (<1 cm thick)

Restricted to the east side of the southwest-trending extension of Cochrane Island, 10o is 'associated with' (see above) the thickly laminated siltstone-argillite fraction of 10n (station #55, Figure 2.4). Two exposures of 10o occur here, one of which is unstratified and solely conglomeratic (station #55).

2

whereas the second contains 4.9 - 8.3 m thicknesses of arkosic wacke bearing thick laminations (station #60, Figure 2.7). In both places, the coarse sand to granule-size matrix grains consist almost entirely of blue-grey quartz.

At station #55, stratification is not developed within the conglomerate, in the sense that bedding cannot be discriminated by changes in clast size. Sizes of the clasts range from pebbles to boulders with most being in the large cobble-size class (Plate 2.14). Figure 2.8 shows the size distribution of clasts greater than 1.0 cm. The largest clast recorded in unit 10o at station #55 has a maximum apparent dimension of 57 cm.

Unlike #55, stratification at station #60 is defined both by changes in clast size and by sections of arkosic wacke containing thick laminae (0.7 - 1.0 cm). Figure 2.7 shows that the two strata-types lie above a 6.5 m (min.) section of unstratified conglomerate.

Conglomerate 10o is matrix-supported and has a clast:matrix ratio of about 1:1 (based on point-counting of lithic clast types, see Chapter 4). Visual estimates during counting revealed that the clasts are angular to subrounded. Imbrication is absent.

Figure 2.7 Measured section through unit 10o (facies 10-3) at station #60, which is on the east side of the southwest-trending extension of Cochrane Island (Figure 2.4). Sample #60 (taken at this locality) is referred to in Chapter 3.

conglomerate

very coarse sand to granule-grade matrix

thick diffuse laminae

normal grading

shear surface

Figure 2.8 Distribution of clast sizes by frequency for individual beds of conglomeratic units 10o (station #55), 10p1 (station #73), and 10r (station #1221). The size data was collected during 400 point grid-counts of the three units. Clasts measuring less than 1.0 centimetre in apparent long dimension are not shown on the histogram. N = number of measurements, $\bar{x}$ = arithmetic average, and SD = standard deviation.

Facies 10-3, unit 10o

Facies 10-4, subunit 10p1

Facies 10-4, unit 10r

General Interpretation of Ungraded, Arkosic Wacke-supported
Conglomerate (facies 10-3)

As previously mentioned (p. 76), facies 10-3 consists of only one unit, 10o. Because of its high matrix content (49.2% from point-count) and broad range of clast sizes (0.03 - 1.4 m), unit 10o is interpreted as a mass flow deposit (alluvial mid-fan). This contrasts with the overlying units of facies 10-4 (10p, 10q and 10r), which are inferred to represent fluid flow deposition in stream-channels (see p. 95-97).

The matrix, but not the framework, composition of unit 10o is comparable (arkosic wacke) to that of the mass flow deposits (10a and 10b) at the base of the previous cycle of alluvial fan sedimentation (facies 10-1 and 10-2). Units 10a and 10b are characterized by clasts of tonalite (6a), whereas clasts of feldspathic wacke (10m) and siltstone (10n) typify conglomerate 10o. Both units 10m and 10n belong to the "well-stratified feldspathic wackes and siltstones (facies 10-2)", and hence it is proposed that partial erosion of the "first" alluvial cycle, together with a more removed, plutonic source (possibly Pitch Pipe Island tonalite 6f), provided detritus for a "second" cycle of alluvial fan deposition (facies 10-3 and 10-4).

Exposures of unit 10o are not extensive (stations 55 & 60, Figure 2.4) (i); and 10o is the only coarse-grained fragmental unit in facies 10-3 and 10-4 which the author attributes to mass flow deposition (ii). These two points contribute to the mid-fan interpretation for facies 10-3, because 'low viscosity', coarse-grained mass flow deposits (10o) are

apparently minor, relative to coarse-grained deposits attributed to fluid flow (10p, 10q and 10r, Figure 2.1 in back pocket). According to Bull (1972, p. 81), the proportion of 'high viscosity' debris flow deposits decreases downfan from the apex in those fans where both water-laid and debris-flow deposits occur, and hence one might expect a higher ratio of mass flow: fluid flow deposits (both coarse-grained) for sediments deposited in a proximal fan environment. Although humid-region fans can be constructed entirely by fluid flow (e.g., Kosi River fan, Gole and Chitale, 1966; Van Horn fan, McGowen and Groat, 1971), the presence of at least 'some' mass flow deposits in facies 10-3 and 10-4 supports the above interpretation.

Detailed Interpretation of Facies 10-3 (unit 10o)

Similar to unit 10b (regolithic arkosic wacke), but compositionally distinct and spatially removed from it, is the matrix-supported, typically unstratified, and poorly sorted conglomerate of unit 10o. As in 10b, the clay-deficient matrix consists of coarse sand to granules, and hence a debris flow origin *sensu stricto*, involving a viscous matrix with strength, is unlikely for unit 10o. Deposition from a high-concentration dispersion (mass flow) is therefore inferred.

Because 10o was observed at two somewhat different exposures, specific mention is made of each. In both places (stations 55 & 60), the type of support (i.e., matrix) is compatible with interpretations of modern sandy mass flows.

First, Bagnold (1956) suggested that in cohesionless mixtures with low viscosities and highly concentrated grain masses, dispersive pressure would overcome clast (pebble to boulder) interlocking. More recently, Rodine and Johnson (1976, p. 213) proposed that very poor sorting of the granular phase inhibits interlocking of clasts and promotes movement. Although packing characteristics of conglomerate 10o have not been analyzed in detail, a comparison of Plate 2.14 with Rodine and Johnson's Figure 1 serves to emphasize the similar sorting of 10o to their "debris flows".

At the two stations, the absence of both stratification and fabric in the conglomerate fraction, implies that the clasts were mutually restricted in movement during transport. Notably absent are clasts concentrated into nests, which have been ascribed to clast migration into the zones of least internal shear of a mass flow (Bagnold, 1954). However, similar features can be produced by "pebble in sand" transport in sandy fluvial settings (Koster, 1977, p. 92). At station #60 (Figure 2.7), thicknesses of arkosic wacke (up to 8.3 m) containing thick diffuse laminations, may represent grain flow during a temporary hiatus in the supply of pebble- to boulder-size clasts (cf. Stauffer, 1967).

The size (up to 1.4 m) and angularity of framework clasts concurs with deposition by mass flow processes; however, subangular to angular clasts are not a requisite feature of mass flow deposits, considering that rapid rates of mechanical abrasion have been recorded in areas of high slope (i.e.,

volcanic regions) by Davies et al. (1978) and Pearce (1971). In the case of 10o, the framework components (clasts of units 6f1., 10m, 10n), but not the matrix (bluish quartz), lithologically resemble the immediately underlying rocks, suggesting that deposition is proximal (but not necessarily adjacent) to the source of detritus (mid-fan environment).

Facies 10-4 Inversely graded → ungraded framework-dominated conglomerates

This regional facies is best exposed on Long Island, its small neighbouring islands, and on most of Cochrane Island (Figure 2.4). It has a maximum exposed thickness of 400 m (unit 10r) on the southeast shore of Cochrane Island (Figure 2.1 in back pocket).

As mentioned in the preamble to facies 10-3, unit 10n (facies 10-2) was observed to underlie all units contained in facies 10-4. But the clast composition, and proximity of conglomerate 10o (10-3) to overlying unit 10r (10-4, station #54), has prompted the author to place 10o in a facies older than 10-4, even though it does not appear below all units of facies 10-4 (i.e., 10p and 10q). Facies 10-4 contains three units in total (10p, 10q, 10r), but is defined by the most abundant conglomeratic beds, which are inversely graded at the base, and ungraded farther up (i.e., 10p1 and 10r). Because unit 10q is intimately associated with 10p, it is considered to be part of facies 10-4.

Unit 10p

Subunit 10p1 - Cobble-pebble conglomerate, inversely graded and framework-supported at base; polymictic, tonalite clasts dominant; two-fold stratification (0.35 - 22.0 m thick)

Subunit 10p2 - Cobble-pebble-boulder conglomerate, ungraded and generally matrix-supported; polymictic, tonalite clasts dominant; +/- feldspathic wacke interlayers (20-40 cm thick)

Subunit 10p3 - Pebble-cobble conglomerate, generally framework-supported; polymictic, tonalite clasts dominant; stratified by planar scours of feldspathic wacke (6-25 cm thick)

As mentioned in the description of 10m, the overlying conglomerate, 10p, dominates the inland portion of Cochrane Island's east-trending arm. The numerical order of the three subunits in 10p (i.e., 1, 2, 3) reflects apparent abundance (approximately equal), but has no chronological significance, because the three are interstratified. This association, the universality of tonalite clasts, and the consistency of matrix composition (feldspathic) and size (2 mm max.), has prompted the author to subdivide 10p rather than create separate units.

At station #73 (Figure 2.4), for example, a 2.5 m thickness of ungraded, matrix-supported 10p2 is truncated by feldspathic wacke (4.5 m thick bed), which in turn, is scoured by an inversely graded and framework-supported bed of 10p1 (4.6 m thick, Plate 2.15).

In detail, the basal scour of this 10p1 bed is planar to gently curved. A layer, up to 30 cm thick, of tightly packed pebble-size (1.5 - 4.5 cm) clasts occurs at the base of the bed,

which grades into a 1.7 m thick zone of medium cobble-size clasts (area of point-count), giving way to abundant pebbles and cobbles (6.5 - 11.5 cm) in the uppermost 2.6 m of the bed. This particular well exposed bed of 10p1 is one of two strata-types present in unit 10p1:

- i) the first, described above, consists entirely of framework-supported clasts (4.5 - 22.0 m thick) which is 'scoured' by another bed of feldspathic wacke (0.8 - 1.0 m thick) (e.g., stations 67 & 73)
- ii) the second is clast-supported at the base (35-60 cm thick), but 'grades' upward into feldspathic wacke (20-30 cm thick), resulting in a conglomerate-sandstone couplet rather than two distinct beds (e.g., station #1190).

In both cases, the framework is inversely graded, whereas the matrix is a medium- to coarse-grained feldspathic wacke which is not visibly graded.

Parts of subunit 10p2, most prevalent along the north shore of Cochrane Island, are strongly sheared because of proximity to a major, east-striking fault zone (Figure 2.1 in back pocket). As a result, it is difficult to determine whether exposures of typically unstratified, matrix-supported conglomerate represent apparent or true thicknesses (0.4 - 4.0 m, station #250). This problem is augmented by 10p2's general lack of facing indicators; for example, wacke interlayers (20-40 cm thick), where present, are tabular (in places due to shearing), but ungraded (station #187).

Subunit 10p3 consists of sharp-based beds of framework-supported conglomerate (12-35 cm thick, local inverse grading) truncated by gently curved medium- to large-scale (6-25 cm thick) cross-beds of feldspathic wacke (e.g., stations 67, 86, 87 and 90, Plate 2.16). The wacke commonly contains "floating" clasts which may or may not be aligned along a common base, and thus the qualification of "generally" framework-supported in the definition of 10p3.

At one locality (station #90, Figure 2.9) a layer of argillite, 1-23 cm thick, appears to drape the conglomeratic bed (10p3). However, the argillite is discontinuous and lensoid, having been scoured by the overlying wacke. Small pebbles lie within and immediately above the disrupted upper parts of plano-concave argillite lenses.

With respect to clast sizes in unit 10p, the aforementioned bed of 10p1 (station #73) was the only site selected for point-count. Size abundances for clasts of 10p2 and 10p3 are approximated in the initial definitions. From point-count, sizes of the 10p1 clasts range from pebbles to boulders, with most being in the medium cobble-size class (Plate 2.15). Figure 2.8 shows the size distribution of clasts greater than 1.0 cm. The largest clast recorded in subunit 10p1 at station #73 is 36 cm.

Subunit 10p1 is framework-supported and has a clast:matrix ratio of about 3:1 (based on point-counting of lithic clast types, see Chapter 4). Clasts are subrounded to rounded (as are clasts of 10p2 and 10p3). Imbrication is rare in 10p1, absent in 10p2 and common in 10p3.

Plates

- 2.16 Conglomeratic beds truncated by planar to gently curved scours of feldspathic wacke (10p3, facies 10-4). Top direction is towards top of photo. Location: south shore of the east-trending arm of Cochrane Island (station #86, Figure 2.4).
- 2.17 Sharp-based couplets of conglomerate and feldspathic green wacke (10r, facies 10-4). Note well developed primary imbrication. Location: south shore of Long Island (station #1207).
- 2.18 Pebble-infilled, gently curved scours within otherwise unstratified feldspathic wacke (unit 11a). Location: east side of the southwest-trending extension of Cochrane Island (station #52).
- 2.19 Sharp-based beds of feldspathic wacke grading into argillite (unit 11b). Note convolute and parallel laminations in the sand-size portion. Location: southeast corner of Miller Island (station #39).
- 2.20 Laterally continuous beds of flat-based feldspathic wacke grading into argillite (11b). Strongly developed fracture cleavage (290°) is most evident in the argillite layers. Location: southeast corner of Miller Island (station #39).

Early Metasedimentary Rocks (Units 4 and 5)

Late Metasedimen

Sample #102-	5	1061	1078	1081	1092B	1100	60	69
Unit	(4a)	(5a)	(4a)	(4a)	(4a)	(4a)	(10a)	(10b)
Framework:								
Quartz (solitary) *	20.00	14.75	34.75	25.50	30.50	13.00	8.00	11.00
Plagioclase (twinned) *	12.00	1.00	2.75	6.75	6.00	1.25	13.25	6.75
Plagioclase (untwinned) *	6.50		2.75	2.00	4.50	1.50	9.00	3.75
Intergrown plag./quartz *		1.25		4.25	2.50	1.00		
PQ rock fragment (m.g.) *	0.50	6.50	5.75	7.50	6.00	3.25	48.00	55.75
Alkali feldspar *								18.25
Intergrown alkali/quartz *	0.50	0.25	2.50	0.75	1.00	1.25	0.25	
PQ rock fragment (f.g.) *	3.50		10.00	1.75	2.00	2.50		0.50
Felsic rock fragment *				1.00	0.25	2.25		
Chloritic rock fragment *		0.25		2.00	0.50	0.25		
Orthoframework:								
Ser-musc-qtz mass *	1.00	1.25	2.25	0.75	3.75	0.25	1.50	
Muscovite								
Sericite								
Biotite								0.50
Chlorite								
Ferroan dolomite								
Epidote (quartz inclusion)				0.25				
Matrix: (includes recryst. clays)								
Quartz *	16.00	24.00	14.75	17.25	12.75	24.25	8.00	1.75
Sericite	1.75	5.25	5.50	4.75	7.00	4.50	2.75	1.50
Biotite							1.75	
Chlorite								
Muscovite								
Pseudomatrix:								
Intergrown plag./qtz	22.50	25.25	9.50	6.75	11.50	17.75		
Ortho-pseudomatrix:								
Muscovite	4.00	8.75		8.50	3.75	3.50		
Sericite		5.25		3.50	4.00	2.00		
Biotite				0.25			4.75	
Chlorite	10.00	3.75		4.50	2.00	4.25		
Ferroan dolomite	0.75			1.25	0.75	14.25		
Epidote				0.25		1.50		
Orthomatrix:								
Ferroan dolomite			7.50				2.00	
Opaque minerals	1.00	2.50	2.00	0.50	1.25	1.50	0.75	0.25

Figure 2.9 Measured section of unit 10n (facies 10-2), overlain by subunit 10p3 (facies 10-4). Section is near the eastern tip of Cochrane Island (station #90, Figure 2.4).

Unit 10q - Subunit 10p2 with argillite interbeds
(1-10 cm thick)

Unit 10q appears at the western end of Cochrane Island's east-trending arm (e.g., stations 157 & 182, Figure 2.4) and on nearby islands (e.g., stations 252, 287 and 344). Argillite interbeds, which are both sharp-based and sharp-topped, almost everywhere occur in ungraded and matrix-supported cobble-pebble-boulder conglomerate (10p2).

The exception is station #157, where beds of non-undulating argillite occur between sharp-based beds of clast-supported (but ungraded) conglomerate, fining upward into feldspathic wacke. The conglomerate is dominated equally by tonalite clasts and argillite rip-ups. Grading of matrix-size grains (2 mm max.) is restricted to the "base" of the lowermost wacke layer.

Unit 10r - Cobble-pebble conglomerate, inversely graded and framework-supported at base (20-40 cm thick) grading into feldspathic green wacke (0.06 - 1.0 m thick); felsic subvolcanic and volcanic clasts prevail

On Long Island, near the mid-central part of the south shore of Cochrane Bay, unit 10r overlies barely exposed beds (water's edge) of feldspathic wacke with argillite interlayers (10m, facies 10-2, station #1208; Figure 2.4). On the east side of the southwest-trending extension of Cochrane Island, 10r overlies unit 10n - also of facies 10-2 (station #47, Figure 2.6). It is this station and numbers 48-50 through which 10r attains a maximum exposed thickness of 400 m.

Cobble-pebble conglomerate (10r) typically occurs in beds

— less than 1.5 m thick (Plate 2.17). The bases of these beds are inversely graded and clast-supported, and are succeeded by an ungraded framework- to matrix-supported zone which grades into medium- to coarse-grained feldspathic green wacke (locally cross-stratified) at the top of the bed. Because the contact between conglomerate and overlying wacke is gradational, the beds are regarded as conglomerate—sandstone couplets rather than separate beds.

The matrix is a medium- to coarse sand-size sediment (2 mm max.). The amount of fine-grained detritus (silt and clay) in these beds is estimated to be less than 10%. There is generally an upward increase in the amount of matrix within a single conglomerate—sandstone couplet, but the matrix shows no discernable trend in size, and the grading therefore is of the coarse-tail variety (Middleton, 1967, p. 503).

Based mainly on a point-count at station #1221, clast sizes range from pebbles to cobbles, with most being in the small cobble-size class (Plate 2.17). Figure 2.8 shows the size distribution of clasts equal to or greater than 1.0 cm. The largest recorded clast in unit 10r at station #1221 is 17 cm.

Unit 10r varies from basally framework-supported to matrix-supported in the upper part of the conglomeratic layer. The ratio of clast:matrix is about 3:4 (based on point-counting of lithic clast types, see Chapter 4). Clasts are subrounded to rounded, and imbrication is common; an isolated current crescent (station #50) and a trailing pebble lag (station #1222) both indicate flow from west to east.

Interpretation of Inversely Graded → Ungraded

Framework-dominated Conglomerates (facies 10-4)

Conglomerate—sandstone couplets, typical of subunits 10p1, 10p3 and unit 10r, exhibit basal inverse grading (Plate 2.15) which appears to be anomalous with a stream-channel or sheet-flood origin. Channelled contacts, diagnostic of stream-channel deposits (Collinson, 1978), are rare; however, Friend (1978) noted the lack of evidence for alluvial incision in ancient sediments, and contrasted this with the tendency for periodic channel incision in recent sediments (Schumm, 1975).

A comparison of the conglomerate—sandstone couplets to gravel bar deposits, shows that the constancy of well-developed beds generally less than 1.5 m thick, and the rhythmic nature of the sand layers, is not typical of documented gravel bar deposits (Eynon and Walker, 1974; Smith, 1974). In addition, normal grading, characteristic of longitudinal bars, is uncommon in all units of facies 10-4. This upward fining in gravel bars has three possible origins (Smith, 1974, p. 219); however, the notion that normal grading is produced during a single waning discharge, is most easily adapted to explain the inversely graded conglomerate of subunits 10p1, 10p3 and unit 10r.

Specifically, Allen (1981, p. 61) points out that, "anticipation of normally graded gravel units appears to disregard the effects of sudden high sediment supply in rather more 'flashy' systems than those studied, for example, by Smith (1970, 1974), Hein (1974) and Hein and Walker (1977)." Allen

states that bedforms and clast-size distributions which are not in equilibrium with flow in the area of entrainment, characterize "flashy" systems (e.g., Fahnestock, 1963). In contrast to normal grading formed by diminishing flows, the flow increases in velocity, enabling it to entrain and transport successively larger clast sizes. If this flow decreases in velocity laterally, it must deposit its load as an inversely graded bed.

The inversely graded beds are most likely stream-channel or bar deposits, but limited exposure of the contacts between units of facies 10-4, renders either interpretation inconclusive. Because the conglomerate—sandstone couplets commonly either overlies siltstone-argillite (10n, facies 10-2) interpreted as overbank fines, or conglomerate 10p2, interpreted as a coarser channel deposit (see below), beds of subunits 10p1, 10p3 and unit 10r may represent individual discharge cycles which built into a migratory bar. Although there are no paleocurrent data to demonstrate a bar environment, the juxtaposition of generally matrix-supported, boulder-bearing conglomerate 10p2 overlain by predominantly pebble-cobble conglomerate—sandstone couplets, can be interpreted as lateral bar growth into adjacent channels, which resulted in a coarse channel deposit (10p2) overlain by finer-grained bar material (10p1, 10p3, 10r; cf. Smith, 1974, Figure 12). This finer-grained bar material apparently can also transect overbank deposits (10n), hence ratifying the proposal of migratory bar deposition in a "flashy" system.

The presence of argillite interbeds within conglomerate 10p2 at the western end of Cochrane Island, suggests that a

significant fraction of clay-size deposition occurred not only on the channel bank (10n), but also within the channel (10q).

Unit 11 of the Cochrane Bay group

Unit 11a - Feldspathic wacke containing planar scours (60 cm wide) infilled by pebbles and granules; sporadic argillite layers (0.5 - 3.0 cm thick)

On the east side of the southwest-trending extension of Cochrane Island, unit 10r (inversely graded conglomerate, facies 10-4) is overlain by 11a (stations 51-52 and 54, Figure 2.4). Because stations 51 and 52 are separated by 80 m of water, the description below applies to strata upsection from this break.

At the base of station #52 (Figure 2.10), 1.5 m of medium- to coarse-grained feldspathic wacke contains a few sharp-topped and non-undulate argillite layers. Above this, a 4-5 m thickness of wacke displays planar scours (40-50 cm thick), defined by thin basal laminae (2-3 mm thick) and infilled by clast-supported cobbles as large as 15 centimetres. The subsequent 20 m of section contains gently curved scours (4.5 - 47.0 cm thick), in which the infilling detritus is significantly finer (i.e., 0.4 - 1.6 cm). In these commonly thinner and finer scours, the clasts may be either matrix- or framework-supported (Plate 2.18).

Clasts consist primarily of felsic volcanics and subvolcanics, and are subangular to subrounded. Distinct imbrication was observed only in a coarser-grained scour near the base

Figure 2.10 Measured section through units 11a, 11b and 11c. Section is from the east side of the southwest-trending extension of Cochrane Island, combining from base to top, stations 52 and 53 (Figure 2.4). Sample 102-2-53A is referred to in Chapter 3.

of the section (Figure 2.10).

Unit 11b - Feldspathic wacke (4-55 cm thick)
grading into argillite (2-3 cm thick);
normal grading common at base of bed

At the north end of station #53, stratigraphically above the described exposure of unit 11a, rhythmic beds of sharp-based feldspathic wacke grade into argillite (11b, Plate 2.19, Figure 2.10). The true thickness of unit 11b at this station is 36 m, but because the north and south ends mark respective limbs of a syncline, the apparent thickness is at least 72 m.

With respect to individual beds at #53, most exhibit normal grading in the basal 2-3 cm of the wacke, then a structureless wacke zone which in the uppermost 1-3 cm diffuses into a non-undulate siltstone-argillite couplet (i.e., A(C)E Bouma divisions). A zone of parallel lamination, between the massive wacke and siltstone divisions, and small-scale cross-lamination in the silt layer (i.e., B and C Bouma divisions) were observed in two beds only. Parallel laminations once may have been present in many of the structureless wacke zones, but subsequent deformation and metamorphism has obscured or obliterated them. Polished slabs show little evidence of lamination in this division.

Eastward along strike of station #53 is Miller Island, where unit 11b dominates the exposure (Plate 2.20). At the southeast corner of the island (station #39), fifty-seven consecutive beds were studied to identify and measure thicknesses of individual Bouma divisions (Figure 2.11). Figure 2.11 shows that almost all of these beds begin with sand-size division A

Figure 2.11 Bouma division thicknesses for fifty-seven consecutive beds at station #39 (Figure 2.4).

(0.2 - 37.9 cm thick) and end with pelitic division E (0.1 - 10.2 cm thick), but that B, C and 'D' (not differentiated on graph) are not consistently developed/preserved.

Unit 11c - Very thin-bedded (1-3 cm) argillite and siltstone

At the stratigraphic top of station #53, bordering the axial plane of the above mentioned syncline, is a 6.5 m thickness of sharp- and flat-based beds of siltstone grading into argillite (Figure 2.10). Unit 11c does not invariably overlie unit 11b; in places it appears as 1-2 m interlayers within 11b.

The nature of individual beds is best seen on small islands east of the southwest-trending extension of Cochrane Island (e.g., stations 36 & 38, Figure 2.4). At station #36, for example, description of 11c beds, and differentiation from those of unit 10n (facies 10-2) is as follows:

- i) the beds, and divisions within the beds, are rhythmic (more so than 10n) and non-undulate (unlike 10n)
- ii) the clay layers (1.0 - 17.0 mm thick) are consistently thicker than the silt layers (0.5 - 9.5 mm thick), whereas they are variable in 10n; nevertheless the average couplet (bed) thickness is approximately equal for both units
- iii) basal concentrations of fine sand-size grains are absent in the silt layers (unlike 10n); small-scale cross-lamination in the silt layers occurs locally (analogous to 10n)
- iv) parallel laminations of silt and clay are commonly developed in the gray-coloured zones between the light

silt and dark clay layers (sporadic in 10n)

v) the uppermost clay layers are massive (analogous to 10n)

With regard to unit 11c, consideration of all points listed above, has prompted the author to interpret observations "iii, iv and v" as CDE Bouma divisions respectively. This interpretation applies also to couplets of unit 10n; however, the CDE sequences are truncated or interrupted in many be

Interpretation of Unit 11

Based on the model of Normark (1970, 1974), the thinning- and fining-upward transition from feldspathic wacke containing pebble-infilled, low-angle scours (11a), through medium to thick beds of feldspathic wacke grading into argillite (11b), to very thin-bedded siltstone and argillite (11c); is compatible with a submarine channel fill (mid-fan) to basin plain sequence.

Unit 11a, at the base of unit 11 (Figure 2.10), is interpreted as an "organized pebbly sandstone" (cf. Walker and Mutti, 1973, p. 126), in which stratification, defined by discontinuous planar scours, is crude and argillite partings are rare. In contrast to the literature, scour-infilling material of unit 11a does not exhibit normal grading, even in the coarse-tail (Plate 2.18). Clasts are simply framework-supported at the base, and become matrix-supported farther up in the "bed". According to Walker (1978), long-distance transport of pebbly sandstones is provided by fluid turbulence, whereas grain interaction (created by dispersive pressure) is a relatively brief and late stage

sediment support mechanism. Evidence of grain interaction is provided by the massive, structureless portion (dominant) of unit 11a, however, discontinuous planar scours within the feldspathic wacke imply at least some traction of grains on the bed.

Most of the beds in unit 11b begin with Bouma division A followed by division E (Plate 2.19); these medium to thick beds would be termed "classical" proximal turbidites by Walker (1967, p. 32). Walker demonstrated statistically that the more beds in a sequence which begin with Bouma division A, the more uncommon is parallel and ripple cross-lamination (B and C divisions) within those beds. This appears to hold true for unit 11b, especially at station #39 (Figure 2.4) where fifty-seven consecutive beds all exhibit A and E divisions, but B, C and D divisions are not consistently developed/preserved (Figure 2.11). It follows, therefore, that "the typical, classical, proximal turbidite is an AE bed, not an ABCDE bed" (Walker and Mutti, 1973, p. 129).

Very thin beds of siltstone grading into argillite represent CDE Bouma sequences (unit 11c). These beds occur as 1-2 m thick interlayers within, and as 6-8 m thick deposits above, unit 11b. In the former situation, exposed 11c/11b contacts are flat-based; there is no indication that thick beds of 11b bifurcated underlying beds of 11c (as might be expected if unit 11c represented levee or interchannel deposition). The interlayers of 11c within 11b, and possibly the thicker deposits of 11c, are interpreted as "classical" distal turbidites (Walker, 1967, p. 32).

Chapter III

PLUTONIC/SEDIMENTARY ROCK COMPOSITION

Petrography of Wackes

Background and techniques

Twenty-seven thin sections of Hayes River Group and Cochrane Bay group sandstones (Figure 3.1) were point-counted to evaluate both provenance and the author's field classification (Hayes River Group versus Cochrane Bay group) of sediments within the Garden Hill Indian Reserve [the classification matches that of Wright (1928), but conflicts with the classifications of Quinn (1960) and Godard (1963a)].

All thin sections discussed in this and the following chapter were stained for both potassium and plagioclase feldspar using the method of Bailey and Stevens (1960). With respect to thin sections selected for point-count analyses, a point distance of 0.5 or 1.0 mm was used, depending on the size of framework grains (range = 0.03 to 1.95 mm). For the coarser units (10a, 10b, 10c), the chart of Kalsbeek (1969) shows that a systematic count of 400 points would result in 310 individual grain counts. An estimate of the reliability, as determined from the chart of Kalsbeek, is: framework quartz (+/-5.5%); framework plagioclase (+/-4.5%) and alkali feldspar (+/-4.2%); matrix quartz (+/-2.5%); all other components (+/-2.0%).

Using an extension of the diverse types of matrix proposed by Dickinson (1970), the metamorphosed wackes were divided into six main components: framework, ortho-framework,

Figure 3.1 Localities of samples selected for microscopic and chemical analyses, together with the five localities (55, 73, 1032, 1061 and 1221) of conglomerate modal analyses (Chapter 4).

53°51' 04"32"

matrix, pseudomatrix, ortho-pseudomatrix and orthomatrix. Framework refers to detrital grains coarser than 0.03 mm. Ortho-framework grains are of similar size, but the only detrital remnant is a faint grain boundary; greenschist facies minerals have replaced the interior parts of such grains. Matrix consists of detrital grains finer than 0.03 mm, as well as recrystallized clay minerals which are interstitial to, but not overprinting, the framework and matrix (i.e., quartz) grains. Pseudomatrix comprises deformed and squashed framework grains, which originally may have been plagioclase, but are now intergrowths of plagioclase (red stain) and quartz. Pseudomatrix commonly is overprinted by metamorphically derived minerals (i.e., ortho-pseudomatrix), whereas minerals which overprint the primary matrix are classified as orthomatrix.

Framework quartz was subdivided into monocrystalline (solitary), and fine- and medium-grained polycrystalline varieties. Polycrystalline quartz (PQ), as defined here, is essentially a quartzose rock fragment consisting of more than one crystal, where no single crystal occupies more than 80% (area) of the rock fragment. Individual crystals are of fine (0.03 - 0.20 mm) or medium (0.21 - 1.95 mm) grain-size; igneous terminology is used here because tonalite batholiths (e.g., Unit 6) are the inferred source of medium-grained polycrystalline quartz (compare Plates 3.1 and 3.2), which is the most abundant type of polycrystalline quartz. Fine-grained polycrystalline quartz, or chert, is much less common.

Description of Samples

The wackes weather light grey to dark greenish-grey; the grey colour becomes progressively lighter with increasing feldspar content. From thin section, the maximum size of framework grains ranges from 0.9 to 1.95 mm, with modes falling between 0.4 and 0.7 mm (medium to coarse sand-size). A gradation from a maximum framework size of at least 1.0 mm through to matrix (less than 0.03 mm) and smaller is present in all the wackes.

The three end-members of the wackes are quartz, feldspar and rock fragments (described below). Because there are some basic differences between the wackes of units 4 & 5 and those of units 10 & 11 (Tables 3.1 and 3.2), these differences warrant incorporation with the end-member descriptions. Subtle variations among wackes of the same unit (e.g., Unit 10) are discussed in the next section.

Quartz:

Quartz is the coarsest framework constituent, occurring as solitary grains and polycrystalline rock fragments. In units 4 and 5 (Hayes River Group), solitary or monocrystalline quartz grains are consistently more abundant than polycrystalline quartz rock fragments (fine- and medium-grained). The converse is true for units 10 and 11 of the Cochrane Bay group. For example, the ratio of monocrystalline quartz to polycrystalline quartz ranges from 2:1 - 5:1, with an average of 3.1 for units 4 and 5; whereas for units 10 and 11, the ratio ranges from 1:16 - 2:1 with an

Table 3.1 Modal analyses of Hayes River Group (Units 4 and 5) and Cochrane Bay group (Units 10 and 11) meta-wackes in volume percent (based on counts of 400 points per thin section). PQ = polycrystalline quartz; plag. = plagioclase feldspar; m.g. = medium-grained (0.21 - 1.95 mm); f.g. = fine-grained (0.03 - 0.20 mm); ser-musc-qtz mass = sericite-muscovite-quartz mass which has a visible grain outline and is replacing a plagioclase or less commonly, an alkali feldspar; recry. = recrystallized; * = component used to plot sample on ternary diagrams (Figures 3.2 to 3.8).

Early Metasedimentary Rocks (Units 4 and 5)

Late Metasedimentary

Sample #102-	6	1061	1078	1081	1092B	1100	60	69
Unit	(4a)	(5a)	(4a)	(4a)	(4a)	(4a)	(10a)	(10b)
Framework:								
Quartz (solitary) *	20.00	14.75	34.75	25.50	30.50	13.00	8.00	11.00
Plagioclase (twinned) *	12.00	1.00	2.75	6.75	6.00	1.25	13.25	6.75
Plagioclase (untwinned) *	6.50		2.75	2.00	4.50	1.50	9.00	3.75
Intergrown plag./quartz *		1.25		4.25	2.50	1.00		
PQ rock fragment (m.g.) *	0.50	6.50	5.75	7.50	6.00	3.25	48.00	55.75
Alkali feldspar *								18.25
Intergrown alkali/quartz *	0.50	0.25	2.50	0.75	1.00	1.25	0.25	
PQ rock fragment (f.g.) *	3.50		10.00	1.75	2.00	2.50		0.50
Felsic rock fragment *				1.00	0.25	2.25		
Chloritic rock fragment *		0.25		2.00	0.50	0.25		
Orthoframework:								
Ser-musc-qtz mass *	1.00	1.25	2.25	0.75	3.75	0.25	1.50	
Muscovite								
Sericite								
Biotite								0.50
Chlorite								
Ferroan dolomite								
Epidote (quartz inclusion)				0.25				
Matrix: (includes recr. clays)								
Quartz *	16.00	24.00	14.75	17.25	12.75	24.25	8.00	1.75
Sericite *	1.75	5.25	5.50	4.75	7.00	4.50	2.75	1.50
Biotite							1.75	
Chlorite								
Muscovite								
Pseudomatrix:								
Intergrown plag./qtz	22.50	25.25	9.50	6.75	11.50	17.75		
Ortho-pseudomatrix:								
Muscovite	4.00	8.75		8.50	3.75	3.50		
Sericite		5.25		3.50	4.00	2.00		
Biotite				0.25			4.75	
Chlorite	10.00	3.75		4.50	2.00	4.25		
Ferroan dolomite	0.75			1.25	0.75	14.25		
Epidote				0.25		1.50		
Orthomatrix:								
Ferroan dolomite			7.50				2.00	
Opaque minerals	1.00	2.50	2.00	0.50	1.25	1.50	0.75	0.25

y Rocks (Unit 10)

441B (10b)	1021-1 (10a)	1032A (10e)	11 (10f)	23 (10f)	1043A (10g)	1047A (10m)	1059A (10m)	49A (10r)	384A (10m)	410A (10k)	440 (10r)
17.75 2.00 3.25 6.67 45.50 15.00 0.50	4.00 19.67 9.00 6.67 42.67	3.25 0.75 47.25 0.50	13.50 4.25 12.00 20.25 1.25 1.75 3.50	18.25 17.75 7.50 8.00 9.00 0.75 3.25	5.50 10.00 5.75 3.75 29.00 0.50	3.00 6.50 5.25 4.75 33.00 0.25	3.75 9.75 9.75 2.00 34.25 0.25	19.25 10.00 10.00 17.50 9.25	10.00 6.75 14.00 27.75 0.50	14.25 6.50 6.00 29.75 0.75 0.50 0.25	13.25 4.75 3.50 21.50 1.00 2.25 2.75
3.25 2.67 7.33 2.00 3.00 0.33			9.75 0.50	5.50 3.00 2.25 7.00 0.50	3.75 0.25	1.25 0.25	0.75	0.50 0.25	0.50	2.50 11.75	1.00 15.75
4.25 5.00	1.67 0.33	4.00	18.75 7.00 4.00	11.25 4.50	8.25 4.50	8.00 0.50	8.00 1.50	17.00 7.25 5.25 1.50 0.50	23.75 1.50	15.75 5.00	19.25 2.50
1.00		28.75			8.50	19.50	15.75		4.00	3.00	11.00
0.25	0.33	9.50 5.75		1.00	2.00 4.00 12.25 0.25 1.50 0.25	1.50 2.00 13.75 0.50 0.50 0.25	1.75 10.50 0.50 1.00 0.25		0.75 2.75 7.25	2.75 0.75	0.50 0.50
1.75 0.50	0.33	0.25	1.50 2.00	0.50	0.25	0.25		1.00 0.75	0.50	0.50	0.25 0.25

2 of 2

ocks (Units 4 and 5)

Late Metasedimentary Rocks (Unit 10)

	1081	1092B	1100	60	69	441B	1021-1	1032A	11	25	1043A	1047A
	(4a)	(4a)	(4a)	(10a)	(10b)	(10b)	(10a)	(10e)	(10f)	(10f)	(10g)	(10m)
5	25.50	30.50	13.00	8.00	11.00	17.75	4.00	3.25	13.50	18.25	5.50	3.00
5	6.75	6.00	1.25	13.25	6.75	2.00	19.67	0.75	4.25	17.75	10.00	6.50
5	2.00	4.50	1.50	9.00	3.75	3.25	9.00		12.00	7.50	5.75	5.25
	4.25	2.50	1.00				6.67			8.00	3.75	4.75
5	7.50	6.00	3.25	48.00	55.75	45.50	42.67	47.25	20.25	9.00	29.00	33.00
					18.25	15.00			1.25	0.75		
0	0.75	1.00	1.25	0.25		0.50			1.75	3.25		
10	1.75	2.00	2.50		0.50			0.50				
	1.00	0.25	2.25									
	2.00	0.50	0.25									
									3.50		0.50	
5	0.75	3.75	0.25	1.50		3.25	2.67		9.75	5.50	3.75	1.25
							7.33		0.50			
					0.50		2.00					
							3.00			3.00		
	0.25									2.25		
										7.00		
							0.33			0.50		0.25
5	17.25	12.75	24.25	8.00	1.75	4.25	1.67	4.00	18.75	11.25	8.25	8.00
0	4.75	7.00	4.50	2.75	1.50	5.00	0.93		7.00	4.50	4.50	0.50
				1.75								
									4.00			
0	6.75	11.50	17.75			1.00		28.75			8.50	19.50
	8.50	3.75	3.50				0.33	9.50		1.00	2.00	1.50
	3.50	4.00	2.00								4.00	2.00
	0.25			4.75		0.25					12.25	13.75
	4.50	2.00	4.25					5.75			0.25	
	1.25	0.75	14.25								1.50	0.50
	0.25		1.50								0.25	
0				2.00		1.75			1.50			
10	0.50	1.25	1.50	0.75	0.25	0.50	0.33	0.25	2.00	0.50	0.25	0.25

(Unit 11)

1059A	49A	384A	410A	440	1212	9	28	35	53A	398A	406
(10m)	(10r)	(10m)	(10k)	(10r)	(10r)	(11b)	(11b)	(11b)	(11b)	(11b)	(11b)
3.75	19.25	10.00	14.25	13.25	8.00	10.25	17.00	20.00	12.50	18.75	23.50
9.75	10.00	6.75	6.50	4.75	3.75	1.25	6.75	8.00	2.75	6.25	6.00
9.75	10.00	14.00	6.00	3.50	6.50	19.25	8.00	12.25	9.00	11.00	4.75
2.00					0.75						
14.25	17.50	27.75	29.75	21.50	30.50	24.25	20.75	12.00	25.25	18.25	18.50
				1.00		2.75	0.25	1.75			0.25
0.25			0.75	2.25	0.25	1.75	0.75	3.00	0.25	0.25	
	9.25	0.50	0.50	2.75	0.75			0.25		2.00	3.00
								0.25			
0.25			0.25			4.00	0.25		1.50		
0.75		0.50	2.50	1.00	0.75	3.00	2.25	0.50	3.75	3.25	1.00
	0.50								1.00		
	0.25		11.75	15.75		0.25			1.75		
						0.75					
8.00	17.00	23.75	15.75	19.25	13.00	15.25	14.00	11.75	22.00	5.50	10.25
1.50	7.25	1.50	5.00	2.50	2.25	7.25	2.00	4.25	12.50	1.00	1.50
	5.25								0.25		
	1.50								2.00		
	0.50					0.25			0.75		
15.75		4.00	3.00	11.00	12.00		6.00	16.75		25.75	21.00
		0.75	2.75	0.50	20.25		12.75	0.75		0.50	2.75
1.75					0.75		6.25				
10.50		2.75	0.75				0.50	4.50		5.00	5.50
0.50		7.25		0.50	0.25		1.25	2.75		1.25	1.75
1.00											
0.25											
	1.00			0.25		7.75	0.25				
	0.75	0.50	0.50	0.25	0.25	2.00	1.00	1.25	4.75	1.25	0.25

Table 3.2 Monocrystalline:polycrystalline quartz ratios and alkali feldspar percentages, for wackes of the Hayes River (4-5) and Cochrane Bay groups (10-11).

Sample #102-	Ratio of mono-crystalline to polycrystalline quartz	Total alkali feldspar in percent
Units 4 and 5		
6 (4a)	5.00	0.50
1061 (5a)	2.27	0.25
1078 (4a)	2.21	2.50
1081 (4a)	2.76	0.75
1092B (4a)	3.81	1.00
1100 (4a)	2.26	1.25
Units 10 and 11		
60 (10o)	0.17	0.25
69 (10b)	0.19	18.25
441B (10b)	0.39	15.50
1021-1 (10a)	0.09	
1032A (10e)	0.07	
11 (10f)	0.67	3.00
25 (10f)	2.01	4.00
1043A (10g)	0.19	
1047A (10m)	0.09	
1059A (10m)	0.11	0.25
49A (10r)	0.72	
384A (10m)	0.35	
410A (10k)	0.47	0.75
440 (10r)	0.55	3.25
1212 (10r)	0.26	0.25
9 (11b)	0.42	4.50
28 (11b)	0.82	1.00
35 (11b)	1.63	4.75
53A (11b)	0.49	0.25
398A (11b)	0.92	0.25
406 (11b)	1.09	0.25

Plates

- 3.1 Medium-grained polycrystalline quartz fragment. Note that mutual grain boundaries are irregular and interlocking. Sample #1212 (10r, facies 10-4). Field of view is 1.65 mm wide.
- 3.2 Polycrystalline quartz and plagioclase of tonalitic unit 6a. Compare internal grain contacts with those of Plate 3.1. Field of view is 1.65 mm wide.
- 3.3 Subangular and angular solitary quartz (clear) grains surrounded by intergrown plagioclase/quartz matrix and pseudomatrix. Sample #1092 (4a). Field of view is 1.65 mm wide.
- 3.4 Plagioclase grain extensively replaced by ferroan dolomite and biotite. Sample #25 (10f, facies 10-2). Field of view is 1.65 mm wide.
- 3.5 Symplectic replacement of twinned plagioclase by quartz. Sample #28 (11b). Field of view is 1.25 mm wide.
- 3.6 Twinned plagioclase grain (centre) is partially replaced by orthoclase (dark fractured area). Tartan twinning (microcline) visible between fractures at left. Sample #69 (10b, facies 10-1). Field of view is 1.25 mm wide.
- 3.7 Boundary of twinned plagioclase grain is overprinted by orthoclase (lower fractured zone). Sample #441B (10b, facies 10-1). Field of view is 1.25 mm wide.
- 3.8 Internal texture of a microporphyritic intermediate volcanic fragment with microphenocrysts of feldspar (twinned) and quartz (clear). Sample #1081 (4a). Field of view is 1.25 mm wide.

average value of 0.6 (Table 3.2). The internal grain boundaries of polycrystalline rock fragments are typically gently curved, but locally are weakly sutured (Plate 3.1). Slight post-crystalline deformation is inferred by the presence of suture-like penetrations along these grain boundaries (Spry, 1969, Plate VII).

With respect to undulatory extinction in quartz, approximately 5-15% of solitary framework grains in wackes of units 4 and 5 do not show undulatory extinction. Of the samples studied from units 10 and 11, only 3-8% of solitary quartz grains are not undulose. Virtually all medium-grained polycrystalline quartz fragments exhibit undulatory extinction.

The borders of monocrystalline quartz grains commonly show resorption or corrosion, but deep embayments are rare. Solitary quartz grains are typically subangular (Plate 3.3) and free of inclusions.

Feldspar:

The staining technique of Bailey and Stevens (1960) revealed that all but two of the wackes selected for point-count analyses contain both twinned and untwinned plagioclase (Table 3.1). Alkali feldspar, percentages of which are considerably lower, is present in all but six thin sections.

The twinned and untwinned varieties of plagioclase are not everywhere easily differentiated. Sericite, muscovite and ferroan dolomite alterations are common to both types of plagioclase, and these can be so pervasive that they obscure or

mask twinning (Plate 3.4). Albite and Pericline twins were noted, with Albite twinning being the most common. In units 4 and 5, the twinned plagioclase is of oligoclase composition, whereas it is of albite-oligoclase composition in units 10 and 11. This is consistent with the concept that sodic plagioclase is the most stable plagioclase type in low-grade metamorphism. Worm-like rods of quartz occur in both twinned and untwinned plagioclase (intergrown plagioclase/quartz in Table 3.1), but complete symplectic intergrowths are rare (Plate 3.5).

Alkali feldspar, most prevalent in wackes belonging to the younger succession of sedimentary rocks, averages 3.8% in units 10 and 11, and 1.0% in units 4 and 5 (Table 3.2). Alkali feldspar is mainly untwinned, suggesting that it is orthoclase or sanidine. Microcline, with its characteristic tartan twinning, appears in only two samples of arkosic wacke from unit 10 (#69, 441B, Figure 3.3). It occurs in individual grains, or together with orthoclase as a metasomatic replacement product of plagioclase (Plate 3.6).

Sericite-muscovite-quartz masses (Table 3.1) are classified as "framework", because they are confined within faint grain boundaries. The prefix "ortho" implies that the original plagioclase (pink) or alkali (yellow) feldspar has been completely replaced by a low-grade mineral assemblage.

Feldspar grains, as a whole, are typically subangular (Plate 3.4); the remainder are considered to be angular. Relative to quartz, feldspar tends to be less rounded and more elongated.

Rock Fragments:

Recognizing that most classification schemes (Gilbert, 1954; Pettijohn, 1957; McBride, 1963) treat polycrystalline quartz grains as part of total quartz, and not as rock fragments, only two fragment types are considered here.

Microporphyritic intermediate volcanic fragments (Plate 3.8) occur in four samples, three of which belong to the older sedimentary succession (Units 4 and 5). Chloritized mafic volcanic fragments have a more widespread distribution, occurring in eleven of the twenty-seven samples selected for point-count. The felsic fragments have sharply defined grain boundaries, whereas the mafic fragments have a squeezed appearance, and commonly grade into matrix material.

Matrix:

Because a major difficulty with sandstone classifications is that the "matrix" may be a secondary transformation of framework grains (Cummins, 1962; Dott, 1964; Pettijohn *et al.*, 1972, p. 206-211), an attempt has been made here to separate primary matrix from pseudomatrix and ortho-matrix (defined on p. 109). The division between pseudomatrix and primary matrix is the most subjective, because the pseudomatrix has indistinct boundaries, and like the detrital matrix, commonly contains quartz (e.g., intergrown plagioclase/quartz). Primary matrix shows evidence of partial recrystallization; it is an interlocking mosaic of mainly quartz, with subordinate amounts of interstitial clay minerals (i.e., sericite, muscovite, chlorite and biotite). Rutile was

observed in one thin section (#9, Figure 3.7).

Discussion of Modal Analyses

Results from point-counting are shown in Table 3.1, where they are arranged in stratigraphic units. The grouping of samples into units is based both on field observations, and compositional similarities gathered from point-counting. Comparable samples are plotted together (after normalizing quartz, feldspar and rock fragments to 100%) on a standard Q-F-RF ternary diagram (Figures 3.2A to 3.7A), and classified according to Williams et al. (1954).

As previously mentioned (p. 106), one of two aims of the point-count analyses was to search for micro-scale differences between sandstones (wackes) of the Hayes River Group (Units 4 and 5) and those of the Cochrane Bay group (Units 10 and 11). The most obvious difference is the amount of medium-grained polycrystalline quartz rock fragments; percentages of which are low (average 4.2%) in units 4 and 5, and high (average 29.1%) in units 10 and 11. Figures 3.2B to 3.7B, and Figure 3.8, have been implemented to illustrate this difference. Liberal amounts of polycrystalline quartz fragments in wackes of units 10 and 11 probably reflect derivation from a quartz-rich plutonic source (i.e., Unit 6, compare Plates 3.1 and 3.2). In contrast, wackes of units 4 and 5 (Figure 3.8) possess greater proportions of solitary quartz grains (average 23.1%), compared to samples of units 10 and 11 (average 12.1%). The high quantity of monocrystalline quartz in wackes of units 4 and 5, together with numerous

Figure 3.2A Standard Q-F-RF ternary diagram (Q = total quartz; F = total feldspar; RF = rock fragments other than chert and medium-grained polycrystalline quartz). Samples from unit 4a (6, 1078, 1081, 1092B and 1100) and unit 5a (1061) plot as feldspathic wackes (Williams et al., 1954).

Figure 3.2B Modified Q-F-RF ternary diagram (Q = solitary framework, chert and matrix quartz; F = total feldspar; RF = rock fragments together with medium-grained polycrystalline quartz). Samples are deficient in medium-grained polycrystalline quartz (interpreted to be tonalite-derived), relative to monocrystalline quartz, and hence plot near the Q apex.

A

B

Figure 3.3A Standard Q-F-RF ternary diagram (Q = total quartz; F = total feldspar; RF = rock fragments other than chert and medium-grained polycrystalline quartz). Samples from units 10a (1021-1), 10b (69 and 441B), 10e (1032A) and 10o (60), plot as arkosic wackes (Williams et al., 1954). All five samples have 'un-normalized' feldspar totals of at least 25 percent (Table 3.1).

Figure 3.3B Modified Q-F-RF ternary diagram (Q = solitary framework, chert and matrix quartz; F = total feldspar; RF = rock fragments together with medium-grained polycrystalline quartz). Samples are enriched in medium-grained polycrystalline quartz (interpreted to be tonalite-derived), relative to monocrystalline quartz, and hence plot near the RF apex.

A

B

Figure 3.4A Standard Q-F-RF ternary diagram (Q = total quartz; F = total feldspar; RF = rock fragments other than chert and medium-grained polycrystalline quartz). Samples from unit 10f (11 and 25) 'plot' as arkosic wackes. However, sample #11 has an 'un-normalized' feldspar total of only 19.25 percent (Table 3.1), which is within the limits of a 'feldspathic' wacke.

Figure 3.4B Modified Q-F-RF ternary diagram (Q = solitary framework, chert and matrix quartz; F = total feldspar; RF = rock fragments together with medium-grained polycrystalline quartz). Samples exhibit approximately equal amounts of medium-grained polycrystalline quartz and monocrystalline quartz, and hence plot midway between the Q and RF apexes.

A

B

Figure 3.5A Standard Q-F-RF ternary diagram (Q = total quartz; F = total feldspar; RF = rock fragments other than chert and medium-grained polycrystalline quartz). Samples from units 10g (1043A) and 10m (1047A and 1059A) 'plot' as arkosic wackes. However, 'un-normalized' feldspar totals range from 16.5 to 21.7 percent (Table 3.1), which is within the limits of a 'feldspathic' wacke.

Figure 3.5B Modified Q-F-RF ternary diagram (Q = solitary framework, chert and matrix quartz; F = total feldspar; RF = rock fragments together with medium-grained polycrystalline quartz). Samples are enriched in medium-grained polycrystalline quartz (interpreted to be tonalite-derived), relative to monocrystalline quartz, and hence plot near the RF apex.

A

B

Figure 3.6A

Standard Q-F-RF ternary diagram (Q = total quartz; F = total feldspar; RF = rock fragments other than chert and medium-grained polycrystalline quartz). Samples from units 10k (410A), 10m (384A), and 10r (49A, 440 and 1212), plot as feldspathic wackes (Williams et al., 1954). 'Un-normalized' feldspar totals are between 10 and 25 percent (Table 3.1).

Figure 3.6B

Modified Q-F-RF ternary diagram (Q = solitary framework, chert and matrix quartz; F = total feldspar; RF = rock fragments together with medium-grained polycrystalline quartz). Samples are enriched in medium-grained polycrystalline quartz (interpreted to be tonalite-derived), relative to monocrystalline quartz, and hence plot near the RF apex.

A

B

Figure 3.7A Standard Q-F-RF ternary diagram (Q = total quartz; F = total feldspar; RF = rock fragments other than chert and medium-grained polycrystalline quartz). Samples from unit 11b (9, 28, 35, 53A, 398A and 406) 'plot' as feldspathic 'and' arkosic wackes, however, 'un-normalized' feldspar totals range from 11 to 25 percent (Table 3.1), which is within the limits of a 'feldspathic' wacke.

Figure 3.7B Modified Q-F-RF ternary diagram (Q = solitary framework, chert and matrix quartz; F = total feldspar; RF = rock fragments together with medium-grained polycrystalline quartz). Samples are only slightly enriched in medium-grained polycrystalline quartz (interpreted to be tonalite-derived), relative to monocrystalline quartz, and hence plot midway between the Q and RF apexes.

A

B

Figure 3.8 Modified Q-F-RF ternary diagram (Q = solitary framework, chert and matrix quartz; F = total feldspar; RF = rock fragments together with medium-grained polycrystalline quartz). Samples from the Hayes River Group (Δ, Units 4 and 5) are poor in medium-grained polycrystalline quartz (interpreted to be tonalite-derived) relative to wackes of the Cochrane Bay group (•, Units 10 and 11), and hence plot near the Q apex.

quartz grains with resorption rims, quartz lacking abundant inclusions, and unstrained solitary quartz grains, suggests predominant derivation from a volcanic terrane (cf. Blatt et al., 1980, p. 289-290).

Another distinguishing feature is that alkali feldspar has a higher average value in wackes of units 10 and 11, than in comparable samples of units 4 and 5 (see p. 117). Alkali feldspar is most abundant in arkosic wacke unit 10b (Table 3.2), which repeatedly grades out of tonalite unit 6a along the south shore of Cochrane Bay, and hence defines the base of the younger succession of sedimentary rocks. Because microcline and orthoclase were observed as replacement products within plagioclase grains of unit 10b (Plates 3.6 and 3.7), it is not certain what percentage of alkali feldspar is detrital. However, be it detrital or metasomatic, high amounts (average 16.9%) of alkali feldspar in unit 10b, relative to wackes farther upsection, reflect limited transport of tonalite-derived elements necessary for alkali feldspar deposition/formation (i.e., lateral distance of 40-50 centimetres across the tonalite (6a)/arkosic wacke (10b) contact).

Geochemistry

Introduction

Ten of the twenty samples selected for chemical analysis were also chosen for detailed thin section examination (see modal analyses, Table 3.1). Two of the chemistry samples are wackes from the Hayes River Group (unit 4a); and fifteen are wackes from the Cochrane Bay group (Units 10 and 11). Three samples of igneous rocks from the Bella Lake Pluton (unit 6a) have the chemistry of tonalites. Sample localities are shown in Figure 3.1. These samples were analyzed by atomic absorption at the analytical lab of the Manitoba Department of Energy and Mines in Winnipeg. The analyst (M. L. J. Weitzel) used "rapid" solution analyses; the solution was prepared by fusing 100 mg of sample with 1.5 g of lithium metaborate-tetraborate flux. The fused sample was dissolved in 100 ml of dilute acid, and this solution was analyzed for: Al, total Fe as Fe_2O_3 , Ca, Mg, Na, K, Ti, Mn, Cr, Cu, Ni, Rb, and Sr. Si and P were determined colorimetrically, and separate portions of sample were taken for auxiliary analyses of ferrous iron, carbon dioxide, sulphur and water. The results are shown in Tables 3.3 and 3.4.

U. S. Geological Survey rock standards AGV-1 and GSP-1 (Abbey, 1978), and C.R.P.G. standard GA (Abbey, 1977) were run three times each as unknowns, together with the other specimens. Relative precision, calculated from the replicate analyses of these standards, is a maximum $\pm 11.12\%$ (TiO_2 of GA) to $\pm 0.02\%$ (MgO of AGV-1). Accuracy, given as percent difference from Abbey

Table 3.1 Chemical analyses of Unit 4 (Mayap River Group)
and Units 10 & 11 (Cochrane Bay Group) wackes.

Sample #101-	10928	1100	1030C	11	1122	1043A	1047A	1059A	49A	51	1212	53A
Unit	(4a)	(4a)	(10b)	(10f)	(10f)	(10g)	(10a)	(10a)	(10a)	(10a)	(10a)	(11a)
SiO ₂	71.65	67.03	65.63	71.80	66.40	70.60	70.45	69.90	74.05	75.25	71.85	74.10
Al ₂ O ₃	11.36	10.66	17.23	13.01	15.98	12.83	14.05	14.67	11.56	11.77	12.21	12.11
FeO ₂	0.87	0.94	1.25	0.65	0.79	0.97	0.43	0.34	0.72	0.52	1.03	0.67
FeO	5.64	5.55	2.78	3.02	2.67	2.51	3.02	2.77	2.78	2.78	3.26	3.21
CaO	1.12	4.38	2.23	1.07	2.13	2.00	2.10	2.10	1.18	1.38	1.30	0.88
MgO	2.62	2.71	1.56	1.98	1.67	1.63	1.78	1.76	1.65	1.82	1.04	2.25
Mn ₂ O	2.05	1.44	2.59	2.98	3.00	4.11	4.39	4.90	2.90	2.80	1.90	2.01
K ₂ O	1.24	1.15	4.20	2.27	3.59	2.79	2.34	1.44	2.77	2.22	2.98	2.38
Ti O ₂	0.62	0.62	0.28	0.48	0.28	0.34	0.41	0.34	0.34	0.41	0.41	0.48
P ₂ O ₅	0.07	0.07	0.06	0.09	0.04	0.06	0.10	0.09	0.06	0.06	0.10	0.09
Na ₂ O	0.09	0.16	0.05	0.05	0.07	0.06	0.07	0.07	0.07	0.06	0.06	0.07
M ₂ O +/-	2.65	2.40	1.86	1.85	1.14	1.08	0.87	1.10	1.25	1.25	1.25	1.13
S	0.22	0.29	0.17	0.31	0.24	0.02	0.15	0.04	0.21	0.25	0.04	0.13
CO ₂	0.48	3.22	0.36	0.48	0.07	1.25	0.36	0.31	0.48	0.63	0.04	0.02
Other:	0.06	0.11	0.07	0.07	0.09	0.09	0.11	0.12	0.09	0.08	0.10	0.08
Loss S = 0	0.09	0.12	0.07	0.12	0.10	0.01	0.06	0.07	0.06	0.10	0.07	0.06
Total	100.45	100.63	100.27	99.99	100.06	100.45	100.37	100.18	100.04	100.53	100.63	100.29
Cr	190	420	106	240	206	216	270	136	289	232	119	244
Ga	78	78	29	45	36	11	31	21	36	39	18	34
Mn	47	137	26	49	35	31	40	42	30	47	76	68
Rb	35	35	140	90	125	80	70	60	90	85	105	80
Sr	40	50	230	150	230	295	340	385	155	165	180	75
Na ₂ O/K ₂ O	1.65	1.35	0.62	1.31	0.84	1.47	2.05	2.40	1.05	1.26	0.97	0.85
Na ₂ Fe	0.87	0.70	0.61	0.60	0.50	0.27	0.21	0.16	0.61	0.51	0.36	1.20
Cr/FeI	4.04	3.07	4.08	4.90	5.69	6.97	6.75	8.05	5.78	4.94	4.20	1.50
Total Fe as Fe ₂ O ₃	6.94	7.11	4.34	4.01	3.76	3.76	3.79	3.42	3.81	3.61	4.65	4.04

Table 3.4 Chemical analyses across three tonalite (6a)/arkosic wacke (10a, 10b) contacts along the south shore of Cochrane Bay.

Sample #102- Unit	1010A (6a)	1010C (10a)	1020 (6a)	1021D (10b)	1021B (10a)	1021-1 (10a)	1149A (6a)	1150A (10b)
			$\bar{x}$			$\bar{x}$		
SiO ₂	69.55	81.50	75.52	75.30	76.05	75.80	75.17	76.15
Al ₂ O ₃	14.53	8.85	12.02	13.52	13.18	12.43	12.65	12.72
Fe ₂ O ₃	1.27	0.52	0.71	1.13	1.04	0.77	0.63	1.03
FeO	0.87	0.46	1.47	1.55	1.57	2.29	1.41	1.44
CaO	1.93	1.03	1.13	0.26	0.26	0.42	1.21	0.71
MgO	0.87	0.42	0.39	0.36	0.52	0.39	0.46	0.63
Mg ₂ O	3.90	2.12	3.79	1.96	1.39	3.90	4.41	0.85
K ₂ O	4.22	3.56	3.77	3.93	4.07	2.63	2.45	4.09
TiO ₂	0.28	0.21	0.28	0.28	0.21	0.26	0.24	0.28
P ₂ O ₅	0.07	0.02	0.04	0.01	0.01	0.01	0.03	0.04
MnO	0.05	0.04	0.05	0.04	0.03	0.04	0.05	0.04
H ₂ O +/-	0.89	0.56	0.64	1.48	1.45	0.92	0.72	1.67
S	0.27	0.10	0.13	0.19	0.20	0.16	0.08	0.24
CO ₂	0.72	0.51	0.31	0.07	0.05	0.09	0.31	0.07
Other	0.10	0.07	0.05	0.05	0.05	0.03	0.04	0.06
less O = S	0.11	0.04	0.05	0.08	0.08	0.07	0.03	0.10
Total	99.41	99.93	100.25	100.05	100.00	100.09	99.83	99.92
Cr	118	186	179	171	148	176	152	202
Cu	130	79	10	11	32	15	9	24
Ni	11	11	6	8	9	7	5	11
Rb	130	80	110	135	125	95	87	115
Sr	290	175	85	25	25	45	85	40
MgO/K ₂ O	0.92	0.60	1.00	0.50	0.34	1.48	1.80	0.21
Rb/Sr	0.45	0.46	1.29	5.40	5.00	2.11	1.02	2.87
Cr/M1	10.73	16.91	29.83	21.37	16.44	25.14	30.40	18.36
total Fe ₂ as Fe ₂ O ₃	2.24	1.03	2.31	2.85	2.78	3.31	2.20	2.63

$\bar{x}$ = mean values of two or more runs

(op. cit.), is a maximum +50.00 and -14.29 (MnO of GSP-1; P_2O_5 of GSP-1) to +0.07 and -0.03 (SiO_2 of GSP-1; SiO_2 of AGV-1). As a further check on precision, replicate analyses (3) were made of sample #1020, and triplicate samples of 1021-1 and 1149A were analyzed. For the major elements, precision is comparable to values stated for the three standards (above); and for the trace elements, it is a maximum $\pm 31.63\%$ (Cr of 1149A) to $\pm 4.03\%$ (Rb of 1149A).

Unsupported results shown in Tables 3.3 and 3.4 cannot be used to define source rock types. However, the evidence established earlier (p. 119 & 133) that the major sources of detritus probably were quartz-bearing volcanic rocks in units 4 and 5 (Hayes River Group), and quartzose plutonic rocks in units 10 and 11 (Cochrane Bay group), is reflected in the chemical composition.

Discussion of Major Elements

Individual results are shown in Tables 3.3 and 3.4, whereas average values are compared with other early Precambrian wackes in Table 3.5.

Wackes of the older succession of sedimentary rocks (Unit 4, column 1, Table 3.5) are comparable to those of the Sheba (column 5) and File Lake Formations (column 6). Relative to the remaining samples, average SiO_2 values are lower, and total Fe, MgO and TiO_2 values are higher (Table 3.5, Figure 3.9). Because only two wackes of unit 4 (Hayes River Group) were analyzed, caution must be used in comparing these results. Nonetheless,

Table 3.5 Average major element composition of Unit 4 wackes, 6a-tonalites, and Unit 10 wackes (in wt. percent).

	1	2	3	4	5	6	7	8	9
SiO ₂	69.35	73.41	75.07	71.56	66.20	65.07	63.20	75.93	80.50
Al ₂ O ₃	11.01	13.07	12.99	13.26	10.20	15.03	15.30	9.41	7.85
Fe ₂ O ₃	0.80	0.87	0.96	0.68	7.01*	0.93	0.99	1.17	0.55
FeO	5.59	1.25	1.68	2.85		5.78	4.26	2.35	2.35
CaO	2.75	1.42	0.82	1.66	1.97	2.62	2.76	2.34	1.75
MgO	2.66	0.57	0.65	1.92	4.50	2.66	3.42	2.77	1.20
Na ₂ O	1.74	4.03	2.13	3.50	1.80	2.92	3.51	2.06	0.50
K ₂ O	1.19	3.48	3.74	2.56	1.58	1.54	2.09	1.67	0.90
TiO ₂	0.62	0.27	0.25	0.38	0.52	0.51	0.50	0.16	0.33
P ₂ O ₅	0.07	0.05	0.02	0.08		0.19	0.11	0.19	0.03
MnO	0.12	0.05	0.04	0.07	0.07	0.08	0.07	0.06	0.09
H ₂ O +/-	2.52	0.75	1.32	1.21		1.61	2.37	0.78	1.70
CO ₂	1.85	0.45	0.19	0.38		0.29	0.51	1.11	1.05
Other	0.23	0.16	0.16	0.19				0.05	
Na ₂ O/K ₂ O	1.46	1.16	0.57	1.37	1.14	1.90	1.68	1.23	0.55

1. Average of unit 6a wackes (Hayes River Group, from Table 3.3).

2. Average of unit 6a tonalites (from Table 3.4).

3. Average of units 10a and 10b arkosic wackes, (Cochrane Bay group, from Tables 3.3 and 3.4).

4. Average of Unit 10 wackes (feldspathic) not included in 3 (above), (Cochrane Bay group, from Table 3.3).

5. Average of 17 Sheba Formation wackes (Condle et al., 1970).

6. Average of 9 File Lake Formation wackes (Bailes, 1980 a,b).

7. Wacke from Knife Lake Group (Goldich et al., 1972; Olakanges, 1972).

8. Average of 3 quartz-rich wackes from formation K (Ayres, 1974).

9. Average of 2 South Bay Group quartz wackes (Donaldson and Jackson, 1965; Wood, 1977, 1980).

* total Fe as Fe₂O₃

Figure 3.9 Total Fe as Fe_2O_3 , MgO - Na_2O - K_2O composition diagram showing the range of unit 4a feldspathic wackes (1), units 10a and 10b arkosic wackes (2) and units 10f, 10g, 10i, 10m, 10r, and 11b feldspathic wackes (3).

- Δ Sheba Formation wackes, South Africa
- ◊ File Lake Formation wackes, Manitoba
- Knife Lake Group wacke, Ontario

differences between the Hayes River (column 1) and Cochrane Bay (columns 3 and 4) values for wackes are substantial: Hayes River samples are lower in SiO_2 , Na_2O , K_2O , and higher in total Fe, MgO , TiO_2 , and MnO .

As expected from thin section work, SiO_2 abundances are relatively high for the Cochrane Bay group (Units 10 and 11), even though average SiO_2 values (columns 3 and 4, Table 3.5) remain lower than those for quartz-rich wackes of formation K (column 8) and the South Bay Group (column 9). Predictable from the high proportion of feldspars, arkosic wackes 10a and 10b (column 3) have higher Al_2O_3 contents than the quartz-rich wackes. The $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio (0.57), quartz range (48-69%, Table 3.1), and average SiO_2 content (75.07%) of the unit 10 arkosic wackes, are comparable to quartz-intermediate wackes (Crook, 1974; Maynard *et al.*, 1980). However, the high $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio of units 10a and 10b is attributed to potassium metasomatism of plagioclase feldspar; a phenomenon present in at least two of the arkosic wackes (Plates 3.6 and 3.7), and therefore, the $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio is here not a reliable indicator of maturity.

In addition, arkosic wacke units 10a and 10b commonly grade out of their inferred source rock (tonalite 6a, Table 3.4, Figure 3.10) within a few centimetres, and close examination is required to distinguish them from the plutonic rock. Therefore, the high quartz and SiO_2 values (quoted above) of units 10a and 10b are a function of detritus derived solely from a quartz-rich plutonic terrane; they are not indicators of a mineralogically mature wacke. Across the 1020/1021 tonalite/arkosic wacke

Figure 3.10 $\text{CaO} - \text{Na}_2\text{O} - \text{K}_2\text{O}$ composition diagram showing the relative positions of unit 6a tonalites ($\square$) and unit 10a, 10b arkosic wackes ($\cdot$). After Condie (1967).

contact (Table 3.4), the $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio does decrease, but then rises significantly with increased distance (#1021-1 at 6 metres) from the igneous rock. This rise, together with progressively smaller percentages of alkali feldspar in wackes farther upsection from the tonalite/arkosic wacke contact (Table 3.2), is believed to represent a lessened effect of potassium-enriched metasomatic fluids on the plagioclase feldspars. Furthermore, $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratios greater than one persist throughout units 10f, 10g, 10i, 10m and 10r (Tables 3.3 and 3.5, column 4), which are stratigraphically above the 6a/10a, 10b contact, and are interpreted as 'downstream' lower alluvial fan deposits (see Chapter 2). These units have high soda contents (average 3.50%) and $\text{Na}_2\text{O}/\text{K}_2\text{O}$ values (>1.0), which are typical of "immature wackes" (Middleton, 1960, p. 1017; Pettijohn, 1963, p. S6); this is not surprising if one accepts the above explanation for the low (<1.0) ratios of $\text{Na}_2\text{O}/\text{K}_2\text{O}$ in the mid-fan deposits of 10a and 10b.

Trace Elements

All samples were analyzed for Cr, Cu, Ni, Rb and Sr; the individual results are shown in Tables 3.3 and 3.4 and the averages in Table 3.6.

In comparison to metabasalts (column 9, Table 3.6) and basaltic andesites (column 10), unit 4a wackes (column 1) have higher average values for Cr and Ni, and a lower average Sr value. Unit 4a samples are higher in Ni, and much lower in Rb and Sr than the granodiorite-quartz diorite compositional range (column 12). Compared to samples of the Sheba Formation (column

Discussion of Conglomerate Point-counts

For easy comparison, results of the five modal analyses are displayed in Table 4.1. In this table, ~~percentages~~ of matrix are stated as percentages of the total rock, but clast percentages are stated as percentages of the framework.

In conglomeratic unit 5a (Plate 2.3), interpreted as the product of deposition in the upper reaches of a submarine channel, 78.1% of the clasts are of clastic sediments. As mentioned in "Recent Work" (p. 21), most sedimentary clasts in unit 5a are compositionally similar to unit 4 rock types (e.g., feldspathic wacke, siltstone and argillite). Thin sections of wacke clasts from station #1061 support this field observation. These clasts have high monocrystalline:polycrystalline quartz ratios and low amounts of alkali feldspar, which is comparable to wackes of unit 4 (Table 3.2). Because the matrix of conglomerate 5a is also similar to unit 4 wackes (Tables 3.1 and 3.2, Figure 3.2), and because relatively few volcanic and plutonic clasts occur in 5a (Table 4.1), and because only 5% of all clasts in unit 5a exhibit a pre-depositional foliation; then the possibility that unit 5a is an intraformational conglomerate of the Hayes River Group (i.e., Units 4 and 5), rather than a deposit which post-dates tonalite (Unit 6) intrusion and erosion is strongly supported.

Conglomerate 10e of facies 10-1 (Plate 2.7), a mid to lower alluvial fan fluid flow deposit, has an arkosic wacke matrix (Figure 3.3) and is dominated by clasts of two, compositionally distinct rock types, namely, tonalitic (56.4%) and mafic

5), which are derived primarily from mafic volcanic rocks (Condie *et al.*, 1970, p. 2768; Eriksson, 1980, p. 25), unit 4a wackes average only one third the amount of Ni, and exhibit lower Rb and Sr values (Figure 3.11).

Figure 3.11 is a Ni versus Rb diagram, on which the Hayes River Group wackes (unit 4a) plot within the andesite-tholeiite field; whereas the Ni-enriched Sheba Formation wackes plot closer to the ultramafic range. Both sets of wackes are interpreted as classical turbidites of submarine origin. Relative to other Precambrian wackes (column 7, Table 3.6) and to granodiorite-quartz diorites (column 12), depleted values of Rb and Sr in the Hayes River and Sheba wackes can be explained as a "dilution effect", caused by a relative abundance of nonalkali and non-alkaline earth-bearing minerals (i.e., quartz, chert, chlorite and limonite; Condie *et al.*, 1970, p. 2767). These authors emphasized the "peculiar Sr depletion" of the Sheba Formation wackes (even lower in the Hayes River Group wackes), and attributed it to a corresponding Sr depletion in the source materials; namely, Sr-depleted basalts. A basaltic source terrane would account for the Hayes River wackes having average Cr and Ni values (column 1, Table 3.6) and total Fe, MgO, TiO₂ and MnO values (column 1, Table 3.5), which are somewhat higher than those of the tonalite-dominated (see p. 119 & 133) Cochrane Bay wackes (columns 3 and 4, Tables 3.5 and 3.6).

In fact, the trace element composition of the Cochrane Bay group wackes (columns 3 and 4, Table 3.6) is most comparable to a granodiorite-quartz diorite (column 12). The low average Sr

Figure 3.11 Ni versus Rb plot of Hayes River and Cochrane Bay group wackes, superposed on diagram from Condle *et al.* (1970).

1. Granites
2. Andesites
3. Continental tholeiites
4. Submarine tholeiites
5. Ultramafic rocks
6. Sheba Formation wackes
- △ Hayes River Group wackes (unit 4a)
- Unit 6a tonalite
- Cochrane Bay group wackes (Units 10 and 11)
- Average crust

value (90 ppm) of the 'alluvial' arkosic wackes (column 3) which flank the south shore of Cochrane Bay near the tonalite (6a)/mafic volcanic (1a) contact, is attributed to source rock control, rather than preferential loss of Sr during weathering and erosion. This is because the average Rb value (115 ppm) is relatively high, and Rb normally is removed more rapidly or at about the same rate as Sr during weathering and erosion (Loughnan, 1969). However, the possibility of preferential Sr loss to pore waters during diagenesis exists, but in such an occurrence, difficulty would be posed by the fact that the feldspathic wackes (column 4) have not been affected. Consequently, small amounts of Sr-depleted mafic volcanic detritus (generated by unroofing of the Bella Lake Pluton) are inferred to have been incorporated with tonalite detritus to form the arkosic wackes of unit 10.

With respect to Figure 3.11 (Ni versus Rb diagram), the arkosic wackes (units 10a and 10b), together with the tonalite samples (unit 6a), plot within the granite field. The samples which lie between the granite and tholeiite ranges are the stratigraphically higher (relative to 10a and 10b) feldspathic wackes of units 10 and 11.

Chapter IV

CLAST COMPOSITION

Background

Clasts and interstitial matrix were point-counted for five different conglomerate units (5a, 10e, 10o, 10pl and 10r) at five representative stations; the station localities are shown on Figure 3.1. Point-counting was facilitated by using the grid pattern of a fishing net, which consisted of 400 points separated from each other by 5 cm. As noted by Donaldson and Jackson (1965, p. 628), point-counting of clasts provides a volumetric basis for percentages of clast types, and ensures that smaller clasts are not overemphasized (as they are in number counts of framework clasts). Drill core samples of clast types were also collected for thin section analysis.

As the conglomerates were being point-counted, the apparent long and short axes of clasts equal to or greater than 1.0 cm were measured. The purpose of these measurements was to provide data for clast-size distribution; discussion of which has been incorporated in the unit descriptions (see Figures 2.3, 2.5 and 2.8) and interpretations of Chapter two.

The types of clasts, together with the amount of matrix, are recorded in Table 4.1. Matrix of the five conglomerates has a maximum size limit of either 2.0 (units 5a, 10pl and 10r) or 4.0 (units 10e and 10o) millimetres, depending on the constancy of granule-grade material.

Table 4.1 Volumetric modal analyses of conglomerates. Four hundred points were counted at each station (Figure 3.1); percentage of matrix is based on the 400 points, but clast percentages are based on the total framework population.

Clast Type	Unit 5a #1061	Unit 10e #1032	Unit 10o #55	Unit 10p1 #73	Unit 10r #1221
Tonalite		56.38	12.31	58.16	3.64
Quartz diorite	2.50			22.79	2.42
Quartz porphyry					4.85
Quartz-feldspar porphyry					30.30
Feldspar porphyry (c.g.; 'unit 6f1')			31.03		3.03
Feldspar porphyry (m.g.)				1.70	9.09
Felsic volcanic					4.85
Porphyritic intermediate volcanic				3.40	15.76
Quartz-feldspar phytic inter. ash	5.08				
Amphibolite (black)		30.87		4.08	3.64
Hornblendite		8.23			0.61
Actinolite-rich rock		2.06			
Gabbro					3.64
Diorite				3.40	15.15
Mafic volcanic		2.06	7.39		
Feldspathic green wacke (c.g.)			29.70		
Feldspathic green wacke (m.g.)			13.26		
Feldspathic wacke	12.71				
Feldspathic lithic wacke	27.81				
Arkosic wacke/tonalite	23.08		6.30	4.76	
Siltstone, argillite	14.41			1.70	
Argillite					
Quartz	6.78	0.41			3.03
Carbonate	7.63				
Matrix	70.50	39.25	49.25	26.50	58.75

Discussion of Conglomerate Point-counts

For easy comparison, results of the five modal analyses are displayed in Table 4.1. In this table, percentages of matrix are stated as percentages of the total rock, but clast percentages are stated as percentages of the framework.

In conglomeratic unit 5a (Plate 2.3), interpreted as the product of deposition in the upper reaches of a submarine channel, 78.1% of the clasts are of clastic sediments. As mentioned in "Recent Work" (p. 21), most sedimentary clasts in unit 5a are compositionally similar to unit 4 rock types (e.g., feldspathic wacke, siltstone and argillite). Thin sections of wacke clasts from station #1061 support this field observation. These clasts have high monocrystalline:polycrystalline quartz ratios and low amounts of alkali feldspar, which is comparable to wackes of unit 4 (Table 3.2). Because the matrix of conglomerate 5a is also similar to unit 4 wackes (Tables 3.1 and 3.2, Figure 3.2), and because relatively few volcanic and plutonic clasts occur in 5a (Table 4.1), and because only 5% of all clasts in unit 5a exhibit a pre-depositional foliation; then the possibility that unit 5a is an intraformational conglomerate of the Hayes River Group (i.e., Units 4 and 5), rather than a deposit which post-dates tonalite (Unit 6) intrusion and erosion is strongly supported.

Conglomerate 10e of facies 10-1 (Plate 2.7), a mid to lower alluvial fan fluid flow deposit, has an arkosic wacke matrix (Figure 3.3) and is dominated by clasts of two, compositionally distinct rock types, namely, tonalitic (56.4%) and mafic

(43.2%) clasts. Approximately 1.6% of the clasts (amphibolite only) are foliated; the remainder are massive. Because unit 10e flanks tonalite 6a along the south shore of Cochrane Bay (Figure 2.1 in back pocket), and an intrusive contact between unit 6a and aphyric mafic flow rocks (1a) occurs at the eastern end of this same shore (Plate 2.4), the tonalitic and mafic clasts are inferred to be products of first-stage unroofing and erosion of the Bella Lake Pluton.

Comparable to unit 10e, conglomerate 10o (facies 10-3) also has a granule-grade arkosic wacke matrix (Figure 3.3). Interpreted as a mid-alluvial-fan mass flow deposit, unit 10o does not, however, contain comparable percentages of tonalitic (12.3%) or mafic (7.4%) clasts; predominant clast types are feldspathic green wacke (43.0%) and feldspar porphyry (31.0%). As mentioned in the "General Interpretation of Facies 10-3" (p. 82), the wacke and siltstone (6.3%) clasts resemble lithologies 10m and 10n, which are the uppermost units of facies 10-2 (Well-stratified feldspathic wackes and siltstones). High percentages of such clasts, together with their angular nature, suggests that these sedimentary units functioned as the primary source of detritus, whereas the less abundant tonalite clasts and blue-grey matrix quartz, suggest a significant, but secondary, plutonic source area. For example, the feldspar porphyry clasts (Plate 2.14) closely resemble subunit 6f1, which outcrops in the bay west of the unit 10o point-count (Figure 3.1), and is interpreted as a marginal phase of the Pitch Pipe Island tonalite (6f, Figure 2.1 in back pocket).

Units 10pl and 10r (Plates 2.15 and 2.17), interpreted as stream-channel deposits of facies 10-4, display an increased number of tonalite clasts (58.2% in 10pl) compared to conglomerate 10o, succeeded by a high abundance of felsic subvolcanic and volcanic clasts (67.9% in 10r). In conglomerate 10pl, only 7.6% of the tonalite clasts are foliated, whereas at least 71.7% of the quartz diorite clasts (22.8%) are foliated; this may represent input from two distinct source terranes [e.g., unit 6c (Chapin Bay tonalite, Figure 2.1 in back pocket), and pre-supracrustal gneisses not exposed in map area]. Clasts of quartz-feldspar porphyry (30.3%) and quartz phyrlic intermediate to felsic volcanic rocks (20.6%) typify conglomerate 10r. A plausible source of these clasts is the area of "felsic meta-volcanic and associated intrusive rocks" (Unit 9), exposed in the southwestern corner of the map area (Figure 2.1). Foliated clasts of any type approximate 2.4%, and the matrix of unit 10r is a feldspathic green wacke (Figure 3.6).

Chapter V

SUMMARY AND CONCLUSIONS

(1) The oldest rock types investigated in detail in the study area are, based on the definition of Wright (1928), the uppermost units (4 and 5) of the Hayes River Group (Table 1.3). Units 4 and 5 are stratigraphically above mafic to felsic metavolcanic (1-2) and associated metasedimentary rocks (3).

Marine deposition below storm wave base is represented by sand-rich beds of classical turbidites (4a, Plate 2.1), and to a lesser extent, by typically unstratified channel-fill conglomerate (5a, Plate 2.3). The scoured nature of the 4a/5a contact on Dutile Island (Plate 2.2), together with matrix and clasts of conglomerate 5a which resemble unit 4 rock types (Table 4.1), has prompted the author to propose uplift (possibly attributable to doming of the Bella Lake Pluton, 6a) of unit 4a beds. This allowed successive currents to erode new channel(s), and mass flows to infill them with clast-supported pebble-cobble conglomerate (5a). Where interstratified with unit 5a, very thin-bedded siltstone-argillite couplets (4g) are interpreted as levee and interchannel deposits.

Compositionally, feldspathic wackes of units 4a and 5a (Figure 3.2) have high ratios of monocrystalline:polycrystalline quartz (range = 2:1 - 5:1, Table 3.2) and abundant unstrained solitary quartz grains, many of which exhibit resorption borders. These features, combined with the relatively high Fe, MgO (Figure 3.9) and Ni values, and low Rb values (Figure 3.11) of unit 4a,

suggest derivation from volcanic, and at least in part, mafic source rocks.

(2) The Bella Lake tonalite (6a), sampled at station #1020 on the south shore of Cochrane Bay, gives a U-Pb zircon age of 2886 $\pm$ 7 Ma (Carson, 1984; Turek *et al.*, 1984). Because of the intrusive nature of the 1a/6a contact (Plate 2.4), 2886 Ma is the minimum age for volcanism and sedimentation of the Hayes River Group (Units 1-5).

The present author suggests that an age of 2801 $\pm$ 4 Ma (Carson, *op. cit.*) for the Pitch Pipe Island tonalite (6f) reflects the maximum age of the Cochrane Bay group (Units 10-11), because the lowermost facies (10-1) of unit 10 fringes the Bella Lake (6a) and Pitch Pipe Island (6f) tonalites. This departs from the view of Carson, who proposed that the maximum age of the group is provided by a zircon age of 2765 $\pm$ 18 Ma for the Chapin Bay tonalite (6c; Wanless *et al.*, 1979, p. 50). Carson (p. 69) stated that the Chapin Bay tonalite is overlain by a cobble-boulder conglomerate which forms the "base" of the Cochrane Bay group, but according to stratigraphic evidence, this conglomerate (10p and 10q, facies 10-4) is positioned near the 'top' of unit 10, and hence initiation of Cochrane Bay group deposition may have preceded the unroofing of the Chapin Bay tonalite (6c). A similar argument is put forth for the Linklater and Dog Island porphyries (9f), which were age-dated at 2765 $\pm$ 11 Ma (Carson, *op. cit.*) and interpreted to be cogenetic with the Chapin Bay tonalite. Unit 9f forms part of the "felsic meta-volcanic rocks, related metasedimentary rocks, and subvolcanic

porphyries" (9), which are the probable source of felsic detritus abundant only in conglomerate 10r (facies 10-4, see Chapter 4). Unit 10r is comparable to units 10p and 10q because it is positioned near the stratigraphic 'top' of unit 10.

Carson (op. cit., p. 68) pointed out a problem with the term "Early Plutonic Rocks" (Table 1.3): he stated that the plutons (mentioned above) are lithologically similar, but that they were "intruded over a period of 120 Ma which is about 65% of the total time for the development of the belt". Based on this observation, and the arguments presented in the preceding paragraph, units 6c and 9f could be placed between facies 10-2 and 10-3 of unit 10, but this would incorrectly suggest that there is evidence that the two units 'intruded' facies 10-1 and 10-2.

(3) Non-marine environments in the Cochrane Bay group are represented by cyclical (facies 10-1 → 10-2 and 10-3 → 10-4) mid alluvial fan to fluvial (+/- supratidal) deposits (Figure 5.1). A mid-fan, as opposed to a proximal fan, setting for facies 10-1 and 10-3 is proposed because of the low ratio of mass flow:fluid flow deposits (both coarse-grained), and in the case of facies 10-1, a low ratio of coarse-grained:fine-grained mass flow deposits.

(4) Units 10a to 10e compose facies 10-1, which is identified as "arkosic wacke-dominated fragmental rocks". Clay-deficient regolith units 10a (rubble breccia, Plate 2.5) and 10b (arkosic wacke) grade out of tonalite 6a along the south shore of Cochrane Bay, and are interpreted to be the products of mass flow deposi-

Figure 5.1 Depositional model for the lower Cochrane Bay group (Unit 10). The postulated sequence of events is:

- a) intrusion of the Bella Lake (6a) and Pitch Pipe Island (6f) tonalites into the Hayes River Group (Units 1-5)
- b) tonalite unroofing and deposition of "arkosic wacke-dominated fragmental rocks" (facies 10-1) in a mid alluvial fan setting
- c) sheetflood deposition (in shallow ephemeral channels) of "well-stratified feldspathic wackes and siltstones" (facies 10-2)
- d) doming of the Chapin Bay tonalite (6c) and felsic porphyries (Unit 9) caused strata of facies 10-2 to be uplifted and partially eroded
- e) incorporation of facies 10-2 detritus into an alluvial mass flow "arkosic wacke-supported conglomerate" (facies 10-3)
- f) stream-channel deposition of "inversely graded → ungraded framework-dominated conglomerates" (facies 10-4)

tion; the former by downslope solifluction and the latter by grain dispersion. Pebble-bearing feldspathic green wacke (10d) is inferred to represent a true debris flow deposit, in which clay-water suspensions could have provided the major support for solid grains during flow. The most extensive 'coarse-grained' unit of facies 10-1 is conglomerate 10e, the lowermost beds of which are attributed to fluid flow deposition during flood surges (Plate 2.6). The sharp-based and graded (Plate 2.7) or cross-stratified (Plate 2.8) wacke beds in the 'uppermost' exposures of 10e, are interpreted as the products of deposition during waning flood stages and dune migration, respectively. Because of the stratigraphic position of the trough cross-strata [near the top of the "arkosic wacke-dominated fragmental rocks" (facies 10-1), and below the "well-stratified feldspathic wackes and siltstones" (facies 10-2)], they are interpreted to represent a mid- to lower fan transition.

Samples from facies 10-1 (69, 441B, 1021-1 and 1032, Table 3.1) are arkosic wackes (Figure 3.3) which exhibit low ratios of monocrystalline:polycrystalline (both fine- and medium-grained) quartz (range = 1:16 - 1:3, averages 0.2, Table 3.2). High amounts of medium-grained polycrystalline quartz fragments (averages 47.8%) reflect significant detrital input from the tonalitic plutons of unit 6 (e.g., 6a and 6f). Compared to the remainder of the Cochrane Bay group (10-11), alkali feldspar is most abundant in unit 10b (15.5 and 18.3 percent), which repeatedly grades out of tonalite 6a along the south shore of Cochrane Bay. This high percentage of alkali feldspar corre-

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otherwise unstratified feldspathic wacke (10k), are interpreted as the products of rapid deposition in shallow ephemeral channels. Laterally extensive beds of feldspathic green wacke grading into argillite (10m, Plate 2.11), and associated silt-stone-argillite couplets (10n, Plates 2.12 and 2.13), are explained as in-channel and overbank deposits, which are derived from decelerating (distal) sheetfloods.

* The stratigraphic position of unit 10h (carbonate interbedded with feldspathic wacke unit 10g) is unclear, because of limited exposure and isolation (restricted to two small islands) from the remaining rock types of facies 10-2. Thick layers of carbonate (Plate 2.10), within a section dominated by feldspathic wacke (10g), are interpreted as representative of supratidal sedimentation in the lower alluvial fan.

Samples from facies 10-2 (11, 25, 384A, 410A, 1043A, 1047A and 1059A, Table 3.1) in places border on arkosic wackes (Figures 3.4 and 3.5), but are predominantly feldspathic wackes (Figure 3.6). Ratios of monocrystalline:polycrystalline quartz are slightly higher (averages 0.6, Table 3.2), and amounts of medium-grained polycrystalline quartz are somewhat lower (averages 26.1%, than in samples from facies 10-1 (see p. 158). Percentages of framework feldspar are also lower (averages 21.2% in 10-2, 28.3% in 10-1). Relative to facies 10-1, the above differences (3) may reflect the increased distance between the feldspathic wackes (facies 10-2) and the primary source terrane (tonalites 6a, 6f).

(6) Associated with siltstone-argillite couplets (10n, facies 10-2) on the east side of the southwest-trending extension of Cochrane Island, is facies 10-3 - "arkosic wacke-supported conglomerate". Cobble-pebble-boulder conglomerate 10o (Plate 2.14) is the only unit in facies 10-3. Comparable to unit 10b (arkosic wacke regolith, facies 10-1), this clay-deficient and poorly sorted conglomerate is interpreted to be the product of mass flow deposition.

As previously mentioned (p. 155), facies 10-3 marks the onset of a "second" alluvial cycle in the Cochrane Bay area. The mechanism responsible for the recreation of alluvial conditions is thought to be doming of the Chapin Bay tonalite (6c), and quartz-feldspar porphyry 9f; both of which give zircon ages of 2765 Ma (Wanless et al., 1979; Carson, 1984). Late-stage introduction of these plutonic units is based on the initial appearance of their detritus in units of facies 10-4. There is no clear evidence that they intrude facies 10-1 and 10-2, and hence the numbering scheme has not been changed.

Sample #60 (Table 3.1), the arkosic wacke matrix of unit 10o, plots in the same field as samples from facies 10-1 (Figure 3.3). A high amount of medium-grained polycrystalline quartz (48.0%) reflects the dominance of tonalitic detritus (e.g., unit 6f) in the 'matrix' of facies 10-3; however, unlike facies 10-1, this dominance does not carry over into the 'framework'.

Specifically, clasts of feldspathic wacke (10m) and siltstone (10n) typify conglomerate 10o (Table 4.1). Because these clasts closely resemble the uppermost units of facies 10-2, and

the largest clast observed was an angular block of feldspathic green wacke measuring 1.4 metres in maximum dimension, such sedimentary rocks probably functioned as the primary source of detritus for conglomerate 10o. The less abundant tonalite clasts and arkosic wacke matrix indicate a secondary, but significant, plutonic source area [possibly the Pitch Pipe Island tonalite (6f): some feldspar porphyry clasts resemble subunit 6f1, interpreted to be a marginal phase of the tonalite].

Mean clast size, calculated at the sites of conglomerate point-counts (Figure 2.8), is greatest (21.6 cm) for mass flow deposit 10o (facies 10-3), then decreases for facies 10-4 fluid flow conglomerates 10p1 (15.9 cm) and 10r (8.0 cm). This reduction in clast size, and a decreasing conglomerate/sandstone ratio from unit 10p to unit 10r, are interpreted as reflections of downfan changes.

(7) Facies 10-4, referred to as "inversely graded → ungraded framework-dominated conglomerates", consists of units 10p, 10q and 10r. Contacts observed with other facies include: 10p and 10q overlying units 10m and 10n (facies 10-2, Figure 2.9), and 10r overlying units 10f, 10n (facies 10-2, Figure 2.6) and 10o (facies 10-3). Conglomerate-sandstone couplets of subunits 10p1, 10p3 and unit 10r commonly exhibit basal inverse grading (Plate 2.15), which is attributed to deposition in a "flashy" (highly variable discharge) river system (cf. Fahnestock, 1963). Associated, but ungraded, cobble-pebble-boulder conglomerates 10p2 and 10q are interpreted as slightly coarser channel deposits.

Samples from facies 10-4 (49A, 440 and 1212, Table 3.1) are feldspathic wackes (Figure 3.6). Ratios of monocrystalline: polycrystalline quartz (averages 0.5, Table 3.2) and amounts of medium-grained polycrystalline quartz (averages 23.2%), but not percentages of framework feldspar (averages 14.2%), are comparable to those of samples from facies 10-2 (see p. 160). Facies 10-2 is here compared with 10-4, because these facies represent the feldspathic, fluvial portions of the "first" and "second" alluvial cycles respectively, and are stratigraphically removed (relative to facies 10-1 and 10-3) from their compositionally similar source terranes [(i) tonalites 6a & 6f and (ii) tonalite 6c & unit 9].

The predominant clast type in conglomerate 10p is biotite-bearing tonalite (Table 4.1). These clasts closely resemble, and are inferred to have been derived from, the Chapin Bay tonalite (6c). In conglomerate 10r, however, clasts of quartz-feldspar porphyry and quartz phyrlic intermediate to felsic volcanic rocks are typical. These clasts are thought to have originated from the "felsic metavolcanic and associated intrusive rocks" (Unit 9). A cogenetic interpretation of units 6c and 9f (Carson, 1984, p. 69) gives support to these plutons being the primary source of clasts for conglomerates of facies 10-4.

(8) Unit 11a, at the base of unit 11, overlies inversely graded conglomerate—sandstone couplets (10r, facies 10-4) on the east side of the southwest-trending extension of Cochrane Island (Figure 2.10). The thinning- and fining-upward transition from

pebble-bearing feldspathic wacke (11a, Plate 2.18), through sand-rich beds of classical turbidites (11b, Plates 2.19 and 2.20), to rhythmic siltstone-argillite couplets (11c), is compatible with a submarine channel fill (mid-fan) to basin plain sequence.

The juxtaposition of fluvial conglomerates (facies 10-4) and submarine turbidites (Unit 11), without an intervening episode of shallow marine deposition, may be attributed to numerous fast-moving small plates in the Archean, in contrast to the present-day control of larger plates moving at an average rate of less than one-sixth of the Archean rate (Dewey and Windley, 1981). A small protocontinent, lacking an extensive shelf, could explain the absence of shallow marine deposits between units 10 and 11.

Samples from unit 11b (9, 28, 35, 53A, 398A and 406, Table 3.1) are feldspathic wackes (Figure 3.7). Percentages of undulose, solitary quartz (averages 17.0%) and medium-grained polycrystalline quartz (averages 19.8%) are comparable (based on estimated reliability, p. 106) to those of samples from underlying conglomerate 10r (monocrystalline averages 13.5%, medium-grained polycrystalline averages 23.2%). Fine-grained polycrystalline quartz, or chert, is more noticeable in units 10r and 11b (averages 3.0%) than in the remaining strata of unit 10 (averages 0.5%). This increased amount of chert, together with microporphyritic felsic volcanic fragments in 11b, is interpreted as detrital input from unit 9 (felsic metavolcanic and associated intrusive rocks) to the uppermost units (e.g., 10r, 11b) of the Cochrane Bay group. With respect to conglomerate 10r, the

presence of felsic volcanic detritus in the matrix, corresponds to a preponderance of felsic volcanic and subvolcanic clasts in the framework (Table 4.1).

(9) Fine-grained quartz diorite (12d) and coarse-grained feldspar-quartz porphyry (12d4), sampled on the western shore of Pitch Pipe Island (station #1113), give a concordant zircon age of 2730 Ma (Carson, 1984). Because the two units have intruded metasedimentary rocks of the Cochrane Bay group, 2730 Ma is a minimum age for these rocks.

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APPENDIX

Unit numbers of unit 10 shown on Manitoba Mineral Resources Division Preliminary Maps 1982 I-1 to I-4, and 1983 I-1 to I-3, do not correspond with the units described in this thesis. The former and present unit numbers are listed below:

1982 and 1983 maps

Thesis

10a
10b
10c
10d
10e
10f
10g
10h
10i
10j
10k
10l
10m
10n
10o
10p
10q

10b
10f, 10g
10i
10d
10j
10k
10l
10m
10n
10h
10a
10c
10e
10p
10q
10o
10r

53° 58' 40"

This geological map illustrates the distribution of various rock units and structural features in the Cordierite area. The map includes several labeled units: 10pl, 71, 73, 76, 10k, 61, 10l, 69, 78, 7a, 10r, 34, 55, 10e, 6a, 10bd, 10b, 10c, 10a, 10d, 10e, 10f, 10g, 10h, 10i, 10j, 10k, 10l, 10m, 10n, 10o, 10p, 10q, 10r, 10s, 10t, 10u, 10v, 10w, 10x, 10y, 10z, 10aa, 10ab, 10ac, 10ad, 10ae, 10af, 10ag, 10ah, 10ai, 10aj, 10ak, 10al, 10am, 10an, 10ao, 10ap, 10aq, 10ar, 10as, 10at, 10au, 10av, 10aw, 10ax, 10ay, 10az, 10ba, 10bb, 10bc, 10bd, 10be, 10bf, 10bg, 10bh, 10bi, 10bj, 10bk, 10bl, 10bm, 10bn, 10bo, 10bp, 10bq, 10br, 10bs, 10bt, 10bu, 10bv, 10bw, 10bx, 10by, 10bz, 10ca, 10cb, 10cc, 10cd, 10ce, 10cf, 10cg, 10ch, 10ci, 10cj, 10ck, 10cl, 10cm, 10cn, 10co, 10cp, 10cq, 10cr, 10cs, 10ct, 10cu, 10cv, 10cw, 10cx, 10cy, 10cz, 10da, 10db, 10dc, 10dd, 10de, 10df, 10dg, 10dh, 10di, 10dj, 10dk, 10dl, 10dm, 10dn, 10do, 10dp, 10dq, 10dr, 10ds, 10dt, 10du, 10dv, 10dw, 10dx, 10dy, 10dz, 10ea, 10eb, 10ec, 10ed, 10ee, 10ef, 10eg, 10eh, 10ei, 10ej, 10ek, 10el, 10em, 10en, 10eo, 10ep, 10eq, 10er, 10es, 10et, 10eu, 10ev, 10ew, 10ex, 10ey, 10ez, 10fa, 10fb, 10fc, 10fd, 10fe, 10ff, 10fg, 10fh, 10fi, 10fj, 10fk, 10fl, 10fm, 10fn, 10fo, 10fp, 10fq, 10fr, 10fs, 10ft, 10fu, 10fv, 10fw, 10fx, 10fy, 10fz, 10ga, 10gb, 10gc, 10gd, 10ge, 10gf, 10gg, 10gh, 10gi, 10gj, 10gk, 10gl, 10gm, 10gn, 10go, 10gp, 10gq, 10gr, 10gs, 10gt, 10gu, 10gv, 10gw, 10gx, 10gy, 10gz, 10ha, 10hb, 10hc, 10hd, 10he, 10hf, 10hg, 10hh, 10hi, 10hj, 10hk, 10hl, 10hm, 10hn, 10ho, 10hp, 10hq, 10hr, 10hs, 10ht, 10hu, 10hv, 10hw, 10hx, 10hy, 10hz, 10ia, 10ib, 10ic, 10id, 10ie, 10if, 10ig, 10ih, 10ii, 10ij, 10ik, 10il, 10im, 10in, 10io, 10ip, 10iq, 10ir, 10is, 10it, 10iu, 10iv, 10iw, 10ix, 10iy, 10iz, 10ja, 10jb, 10jc, 10jd, 10je, 10jf, 10jg, 10jh, 10ji, 10jj, 10jk, 10jl, 10jm, 10jn, 10jo, 10jp, 10jq, 10jr, 10js, 10jt, 10ju, 10jv, 10jw, 10jx, 10jy, 10jz, 10ka, 10kb, 10kc, 10kd, 10ke, 10kf, 10kg, 10kh, 10ki, 10kj, 10kl, 10km, 10kn, 10ko, 10kp, 10kq, 10kr, 10ks, 10kt, 10ku, 10kv, 10kw, 10kx, 10ky, 10kz, 10la, 10lb, 10lc, 10ld, 10le, 10lf, 10lg, 10lh, 10li, 10lj, 10lk, 10ll, 10lm, 10ln, 10lo, 10lp, 10lq, 10lr, 10ls, 10lt, 10lu, 10lv, 10lw, 10lx, 10ly, 10lz, 10ma, 10mb, 10mc, 10md, 10me, 10mf, 10mg, 10mh, 10mi, 10mj, 10mk, 10ml, 10mm, 10mn, 10mo, 10mp, 10mq, 10mr, 10ms, 10mt, 10mu, 10mv, 10mw, 10mx, 10my, 10mz, 10na, 10nb, 10nc, 10nd, 10ne, 10nf, 10ng, 10nh, 10ni, 10nj, 10nk, 10nl, 10nm, 10nn, 10no, 10np, 10nq, 10nr, 10ns, 10nt, 10nu, 10nv, 10nw, 10nx, 10ny, 10nz, 10oa, 10ob, 10oc, 10od, 10oe, 10of, 10og, 10oh, 10oi, 10oj, 10ok, 10ol, 10om, 10on, 10oo, 10op, 10oq, 10or, 10os, 10ot, 10ou, 10ov, 10ow, 10ox, 10oy, 10oz, 10pa, 10pb, 10pc, 10pd, 10pe, 10pf, 10pg, 10ph, 10pi, 10pj, 10pk, 10pl, 10pm, 10pn, 10po, 10pp, 10pq, 10pr, 10ps, 10pt, 10pu, 10pv, 10pw, 10px, 10py, 10pz, 10qa, 10qb, 10qc, 10qd, 10qe, 10qf, 10qg, 10qh, 10qi, 10qj, 10qk, 10ql, 10qm, 10qn, 10qo, 10qp, 10qq, 10qr, 10qs, 10qt, 10qu, 10qv, 10qw, 10qx, 10qy, 10qz, 10ra, 10rb, 10rc, 10rd, 10re, 10rf, 10rg, 10rh, 10ri, 10rj, 10rk, 10rl, 10rm, 10rn, 10ro, 10rp, 10rq, 10rr, 10rs, 10rt, 10ru, 10rv, 10rw, 10rx, 10ry, 10rz, 10sa, 10sb, 10sc, 10sd, 10se, 10sf, 10sg, 10sh, 10si, 10sj, 10sk, 10sl, 10sm, 10sn, 10so, 10sp, 10sq, 10sr, 10ss, 10st, 10su, 10sv, 10sw, 10sx, 10sy, 10sz, 10ta, 10tb, 10tc, 10td, 10te, 10tf, 10tg, 10th, 10ti, 10tj, 10tk, 10tl, 10tm, 10tn, 10to, 10tp, 10tq, 10tr, 10ts, 10tt, 10tu, 10tv, 10tw, 10tx, 10ty, 10tz, 10ua, 10ub, 10uc, 10ud, 10ue, 10uf, 10ug, 10uh, 10ui, 10uj, 10uk, 10ul, 10um, 10un, 10uo, 10up, 10uq, 10ur, 10us, 10ut, 10uu, 10uv, 10uw, 10ux, 10uy, 10uz, 10va, 10vb, 10vc, 10vd, 10ve, 10vf, 10vg, 10vh, 10vi, 10vj, 10vk, 10vl, 10vm, 10vn, 10vo, 10vp, 10vq, 10vr, 10vs, 10vt, 10vu, 10vv, 10vw, 10vx, 10vy, 10vz, 10wa, 10wb, 10wc, 10wd, 10we, 10wf, 10wg, 10wh, 10wi, 10wj, 10wk, 10wl, 10wm, 10wn, 10wo, 10wp, 10wq, 10wr, 10ws, 10wt, 10wu, 10wv, 10ww, 10wx, 10wy, 10wz, 10xa, 10xb, 10xc, 10xd, 10xe, 10xf, 10xg, 10xh, 10xi, 10xj, 10xk, 10xl, 10xm, 10xn, 10xo, 10xp, 10xq, 10xr, 10xs, 10xt, 10xu, 10xv, 10xw, 10xx, 10xy, 10xz, 10ya, 10yb, 10yc, 10yd, 10ye, 10yf, 10yg, 10yh, 10yi, 10yj, 10yk, 10yl, 10ym, 10yn, 10yo, 10yp, 10yq, 10yr, 10ys, 10yt, 10yu, 10yv, 10yw, 10yx, 10yy, 10yz, 10za, 10zb, 10zc, 10zd, 10ze, 10zf, 10zg, 10zh, 10zi, 10zj, 10zk, 10zl, 10zm, 10zn, 10zo, 10zp, 10zq, 10zr, 10zs, 10zt, 10zu, 10zv, 10zw, 10zx, 10zy, 10zz, 10aa, 10ab, 10ac, 10ad, 10ae, 10af, 10ag, 10ah, 10ai, 10aj, 10ak, 10al, 10am, 10an, 10ao, 10ap, 10aq, 10ar, 10as, 10at, 10au, 10av, 10aw, 10ax, 10ay, 10az, 10ba, 10bb, 10bc, 10bd, 10be, 10bf, 10bg, 10bh, 10bi, 10bj, 10bk, 10bl, 10bm, 10bn, 10bo, 10bp, 10bq, 10br, 10bs, 10bt, 10bu, 10bv, 10bw, 10bx, 10by, 10bz, 10ca, 10cb, 10cc, 10cd, 10ce, 10cf, 10cg, 10ch, 10ci, 10cj, 10ck, 10cl, 10cm, 10cn, 10co, 10cp, 10cq, 10cr, 10cs, 10ct, 10cu, 10cv, 10cw, 10cx, 10cy, 10cz, 10da, 10db, 10dc, 10dd, 10de, 10df, 10dg,

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LEGEND

PROTEROZOIC

16

- a) diabase, massive
- b) gabbro, massive

15

- a) biotite-granite, medium- to coarse-grained, massive
- b) Pegmatite, pink, potassium feldspar dominant

14

- a) felsic dykes
- b) quartz porphyry, fine- to medium-grained
- c) quartz-feldspar porphyry, medium-grained
- d) feldspar-quartz porphyry, medium- to coarse-grained
- e) feldspar porphyry, biotite-bearing
- f) feldspar porphyry, medium-grained, feldspars rounded, hornblende trails

13

- a) mafic metamorphic dykes
- b) amphibolite, fine- to medium-grained, aphyric or hornblende phyr
- c) amphibolite, medium-grained, plagioclase hornblende phyr
- d) chloritic, fine-grained

12

- a) Late plutonic rocks
- b) biotite-tonalite, medium- to coarse-grained, massive
- c) quartz diorite, medium-grained, hornblende abundant, massive
- d) tonalite, fine-grained, biotite-bearing
- e) quartz diorite, fine- to medium-grained, hornblende bearing
- f) feldspar porphyry, fine-grained, hornblende bearing
- g) feldspar porphyry, fine- to coarse-grained, hornblende-bearing
- h) feldspar porphyry, medium-grained, hornblende-bearing
- i) feldspar-quartz (minor) porphyry, coarse-grained, hornblende-bearing
- j) diorite dyke, fine-grained, hornblende-bearing
- k) diorite dyke, medium-grained, hornblende-bearing

11

- a) Late metasedimentary rocks: turbidites
- b) feldspathic wacke containing planar scour (60 cm wide) infilled by pebbles and granules; sporadic argillite layers (0.5 - 3.0 cm thick)
- c) feldspathic wacke (4-55 cm thick) grading into argillite (2.5 cm thick), normal grading common at base of bed
- d) very thin-bedded (1-3 cm) argillite (dominant) and siltstone

10

- a) Late metasedimentary rocks: regolith
- b) rubble breccia of vein quartz and tonalite blocks (up to 1 m) supported by a very coarse-grained arkosic wacke matrix, unstratified
- c) arkosic wacke, coarse-grained, typically unstratified
- d) unstratified cobble-pebble-boulder conglomerate, clast-supported; subangular tonalite and mafic metavolcanic clasts predominate
- e) chloritic arkosic - feldspathic green wacke, contains granule- and pebble-size fragments, locally stratified
- f) cobble-boulder conglomerate, commonly clast-supported; abundant well-rounded tonalite and subrounded amphibolite clasts, locally trough cross-bedded (7-40 cm thick sets)
- g) feldspathic wacke (siliceous), localized layering of predominantly felsic pebbles and granules
- h) feldspathic wacke (siliceous), sporadically distributed felsic pebbles and rare cobbles
- i) carbonate (0.5 - 1.0 m thick beds) interbedded with unit 10g
- j) intraformational cobble-boulder conglomerate
- k) feldspathic wacke (feldspar-rich), locally cross laminated (3-8 cm thick sets)
- l) argillaceous wacke with quartz granule framework, typically cross-stratified (20-40 cm thick sets)
- m) feldspathic wacke (siliceous) containing sporadic scour (up to 7 m wide) locally infilled with pebbles and granules
- n) granule-bearing feldspathic wacke (0.1 - 1.5 m thick beds) interlayered with argillite (2-10 cm thick)
- o) feldspathic green wacke (5-15 cm thick) with siltstone, argillite and sporadic calcareous interlayers (1-3 cm thick), locally showing normal grading at base of wacke
- p) siltstone (0.2 - 20.0 cm thick) with argillite and sporadic calcareous interlayers (0.1 - 10.0 cm thick)
- q) cobble-pebble-boulder conglomerate, matrix-supported; subangular sedimentary clasts dominant, rare argillaceous laminae (<1 cm thick)
- r) cobble-pebble conglomerate, inversely graded and framework-supported at base; pelitic, tonalite clasts dominant; two fold stratification (0.15 - 22.5 m thick)
- s) cobble-pebble-boulder conglomerate, ungraded and generally matrix supported; only argillite, tonalite clasts dominant; +/- feldspathic wacke interlayers (2.0 - 10 cm thick)

COCHRANE BAY

- k) feldspathic wacke (siliceous) containing sporadic scours (up to 2 m wide) basally infilled with pebbles and granules
- l) granule-bearing feldspathic wacke (0.1 - 1.5 m thick beds) interlayered with argillite (2-20 cm thick)
- m) feldspathic green wacke (5-15 cm thick) with siltstone, argillite and sporadic calcareous interlayers (1-3 cm thick), locally showing normal grading at base of wacke
- n) siltstone (0.2 - 20.0 cm thick) with argillite and sporadic calcareous interlayers (0.1 - 10.0 cm thick)

Facies 10-3

- o) cobble-pebble-boulder conglomerate, matrix-supported; subangular sedimentary clasts dominant, rare argillaceous laminae (<1 cm thick)

Facies 10-4

- p)
 - p1) cobble-pebble conglomerate, inversely graded and framework-supported at base; polyclastic, tonalite clasts dominant; two-fold stratification (0.35 - 22.0 m thick)
 - p2) cobble-pebble-boulder conglomerate, ungraded and generally matrix-supported; polyclastic, tonalite clasts dominant; +/- feldspathic wacke interlayers (20-40 cm thick)
 - p3) pebble-cobble conglomerate, generally framework-supported; polyclastic, tonalite clasts dominant; stratified by planar scours of feldspathic wacke (6-25 cm thick)
 - q) subunit 10p2 with argillite interbeds (1-10 cm thick)
 - r) cobble-pebble conglomerate, inversely graded and framework-supported at base (20-40 cm thick) grading into feldspathic green wacke (0.06 - 1.0 m thick); felsic subvolcanic and volcanic clasts prevail

13

- a) felsic metavolcanic rocks, associated metasedimentary and intrusive rocks
- b) aphyric flow, massive to locally banded
- c) feldspathic ash flow(?) partly brecciated and/or fragmental, lapilli-size fragments of felsic volcanics and quartz
- d) tuff breccia and lapilli tuff
- e) laminated to thinly bedded, fine-grained tuff or tuffaceous sediment
- f) pebble-cobble conglomerate, matrix- to clast-supported, stratified; felsic volcanic clasts predominant, carbonate clasts locally abundant
- g) quartz-feldspar porphyry, medium- to coarse-grained
- h) quartz diorite, medium-grained
- i) feldspar porphyry, fine-grained
- j) quartz +/- feldspar-phyric choritic dyke
- k) gneissic quartz diorite with pegmatitic veins

14

- a) mafic intrusive rocks
- b) meta-gabbro, medium- to coarse-grained
- c) quartz-bearing meta-gabbro
- d) meta-leucogabbro
- e) hornblende
- f) pegmatitic meta-gabbro
- g) diorite
- h) meta-gabbro, fine-grained

15

- a) ultramafic rocks
- b) shallow intrusion or flow; fine-grained
- c) serpentinitized peridotite
- d) talc schist
- e) actinolite schist

16

- a) Early plutonic rocks
- b) Bella Lake tonalite, coarse-grained, hornblende dominant, weakly foliated to massive
 - a1)* megacrystic granodiorite
 - a2)* tonalite, fine-grained
 - a3)* diorite, fine-grained
 - a4)* diorite, medium- to coarse-grained
- c) Vasegomach tonalite, medium- to coarse-grained, hornblende dominant, weakly foliated to massive
 - b1)* tonalite, medium-grained, biotite dominant, foliated
 - b2)* migmatite: intermediate and mafic biotite +/- hornblende gneiss with granitic lit-par-lit injections
- d) Chapin Bay tonalite, medium- to coarse-grained to plagioclase porphyroblastic, biotite dominant, strongly foliated
- e) granodiorite, coarse-grained to porphyroblastic
- f) Jubilee Island tonalite, medium-grained, biotite dominant, massive to weakly foliated
 - a)* plagioclase +/- quartz porphyry
 - b) Pitch Pipe Island tonalite, coarse-grained, biotite dominant, foliated
 - c) feldspar porphyry, medium- to coarse-grained, biotite-bearing aplite

17

- a) Conglomerate
- b) pebble-cobble conglomerate, clast-supported; sedimentary clasts dominant, typically unstratified

18

- a) Epiclastic and chemical metasedimentary rocks
- b) feldspathic wacke (4-20 cm thick) grading into argillite (0.50 - 20.0 cm)
- c) argillite, argillitic siltstone and wacke
- d) intermediate feldspathic wacke and siltstone
- e) felsic feldspathic wacke and siltstone
- f) chert and siliceous siltstone
- g) pebble-cobble conglomerate, matrix-supported; volcanic and sedimentary clasts, unstratified
- h) very thin-bedded (1-2 cm) argillite and siltstone, minor wacke layers
- i) iron formation (hematite-chert, carbonate +/- magnetite-chert)
- j) carbonate

19

- a) Metasedimentary rocks, derived in part from, and interlayered with, felsic pyroclastic deposits
- b) feldspathic wacke interbedded with siltstone and argillite
- c) intermediate feldspathic wacke and siltstone
- d) felsic feldspathic wacke and siltstone
- e) argillite, argillitic siltstone and wacke
- f) chert and siliceous siltstone
- g) pebble-cobble conglomerate, matrix-supported; volcanic and sedimentary clasts, unstratified
- h) very thin-bedded (1-2 cm) argillite and siltstone, minor wacke layers
- i) iron formation (hematite-chert, carbonate +/- magnetite-chert)
- j) carbonate

20

- a) Felsic to intermediate metavolcanic and related intrusive rocks
- b) plagioclase +/- quartz-phyric flow and/or shallow intrusion
- c) plagioclase +/- quartz crystal tuff, minor lapilli tuff
- d) breccia, tuff breccia, minor lapilli tuff

21

- a) Mafic to intermediate metavolcanic and related intrusive rocks
- b) aphyric massive flow and minor gabbro
- c) pillowed flow
- d) amygdaloidal flow
- e) tuff
- f) tuff, coarse ash- and rare lapilli-size fragments
- g) volcanic breccia
- h) chlorite schist
- i) amphibolitic schist
- j) amphibolite, fine- to coarse-grained

7 of

A geological map of the Cochrane Bay Area. The map shows a coastline with several islands and a bay. A scale bar at the bottom indicates a distance of 1 kilometre. The map is titled 'FIGURE 2.1 Geology of the Cochrane Bay Area'.

FIGURE 2.1

Geology of the Cochrane Bay Area

Scale 1:20,000

8 of 1

90F9

- a)* crystal tuff and lapilli tuff
pebble-conglomerate, matrix-supported; polymictic, volcanogenic
- 2
- a)* relate to intermediate metavolcanic and related intrusive rocks
b)* plagioclase +/- quartz-phyric flow and/or shallow intrusion
c)* plagioclase +/- quartz crystal tuff, minor lapilli tuff
breccia, tuff breccia, minor lapilli tuff
- 1
- a)* mafic to intermediate metavolcanic and related intrusive rocks
b)* aphyric massive flow and minor gabbro
c)* pillowed flow
d)* amygdaloidal flow
e)* tuff
f)* tuff, coarse ash- and rare lapilli-size fragments
g)* volcanic breccia
h)* chlorite schist
i)* amphibolitic schist
j)* amphibolite, fine- to coarse-grained
k)* gabbroic amphibolite, fine- to very coarse-grained (in unit 6a)
l)* plagioclase-phyric flow
m)* variolitic flow

*This unit does not occur in the thesis area; limit of geological mapping shown on Figure 1.1. Areas shaded, but not coded, were mapped by C. R. McGregor and V. Weber, 1982.

SYMBOLS

	Area of outcrop
	Small outcrop, area of small outcrops
	Geological contact (defined, approximate, assumed, under water)?
	Bedding, top known (inclined, vertical, overturned, dip unknown)
	Bedding, top unknown (inclined, vertical, dip unknown)
	Transposed bedding (inclined)
	Foliation, schistosity (inclined, vertical, dip unknown)
	Foliation, cataclastic (inclined, vertical, dip unknown)
	Foliation and parallel primary layering (inclined, vertical)
	Foliation and parallel metamorphic layering (inclined, vertical, dip unknown)
	Foliation and parallel cataclastic layering (inclined, vertical, dip unknown)
	Pillow flattening (inclined)
	Fracture cleavage (inclined, dip unknown)
	S-Intersection (bedding plane/foliation planes)
	Mineral lineation (horizontal)
	Deformed clast lineation
	Minor fold axis (inclined, vertical, plunge unknown)
	Minor fold axial plane (inclined, vertical)
	Minor fold symmetry (symmetrical, asymmetrical S-shaped, Z-shaped)
	Shear surfaces (inclined, dip unknown)
	Axial trace of anticline (approximate)
	Axial trace of syncline (approximate)
	Axial trace of overturned anticline (approximate)
	Axial trace of overturned syncline (approximate)
	Fault (approximate)
	Iron formation
	Carbonatized zone
	Silicified zone
	Carbonate vein
	Gossan
	Interbedded sedimentary strata
	Spinifex texture
	No outcrop

1170
1170
1140

94°49'06"

1 of

58°40'

2 of

432

4
23

429
430 428
431 427
426
425

414

1122

623

728

1214
1030
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1021
1020
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323

1146 1140 1137 1138 1139 1145 1197 1199 1198 1196 207 208 206 205 204 209 137 136 135 139 141 1162 1161 1141 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500

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ISLAND

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COCHRANE BAY

FIGURE 2.2

Station Location Ma

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60F6

END

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FIN