**Field Relationships, Petrology, and Petrogenesis of Neoproterozoic
Granitoids in the Northern Migmatite Sub-Domain,
Committee Bay Belt, Nunavut**

Dixon Louis Byrne
B.Sc. (Hons.)

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ABSTRACT

Granitoid rocks comprise over 90% of the exposed geology and extend for up to 500 km along strike from west of Wager Bay through to the southern portion of the Melville Peninsula.

These granitoids are divided into 3 major series including 8 different lithologies. The divisions are: a plagioclase-rich series, a potassium-feldspar-rich series, and a peraluminous series. The plagioclase-rich series is comprised of two types of tonalite and a quartz dioritic unit. These units have $\epsilon\text{Nd}(t)$ values ranging from +0.79 to +3.51 and crystallized ca. 2.72-2.61 Ga. The potassium-feldspar-rich series is comprised of two types of granodiorite and one granitic unit. These rocks crystallized ca. 2.61-2.58 Ga and have $\epsilon\text{Nd}(t)$ values ranging from -2.00 to +0.16. Two granitic units comprise the peraluminous series and contain $\epsilon\text{Nd}(t)$ values ranging from -1.40 to +0.89.

The formation of tonalitic magmas was the result of dehydration melting of amphibolitic source rocks. As a result of tonalite emplacement, crustal thickening occurred and the temperature gradient increased in the mid- to low-crustal levels causing melting/migmatization of sediments. This led to the formation of granodioritic and granitic plutons that are both metaluminous and peraluminous in character.

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TABLE OF CONTENTS

ABSTRACT	ii
ACKNOWLEDGMENTS	iv
TABLE OF CONTENTS	v
LIST OF TABLES	viii
LIST OF FIGURES	viii
LIST OF ABBREVIATIONS A	xiii
LIST OF ABBREVIATIONS B	xiii
 CHAPTER 1: INTRODUCTION	 1-1
1.1 INTRODUCTION	1-1
1.2 SETTING OF THE AREA	1-2
1.3 RESEARCH GOALS	1-3
1.4 METHODOLOGY	1-5
1.4.1 Introduction	1-5
1.4.2 Major and Trace Element Geochemistry	1-5
1.4.2.1 Introduction	1-5
1.4.2.2 Discrimination diagrams	1-6
1.4.2.3 Bivariant diagrams	1-7
1.4.2.4 Normalized rare-earth element and multi-element plots	1-7
1.4.3 Radiogenic Isotopes (Sm-Nd)	1-9
1.5 ORGANIZATION OF THE THESIS	1-11
 CHAPTER 2: REGIONAL GEOLOGY	 2-1
2.1 INTRODUCTION	2-1
2.2 GEOLOGY AND TECTONIC SETTING OF THE RAE DOMAIN	2-1
2.3 GEOLOGY OF THE PRINCE ALBERT GROUP	2-3
2.3.1 Metasedimentary siliclastic rocks	2-5
2.3.2 Metavolcanic rocks	2-6
2.3.3 Migmatitic rocks	2-7
2.4 INTRUSIVE ROCKS	2-8
2.4.1 Walker Lake intrusive complex	2-8
2.4.2 Peraluminous granitoids	2-8
2.4.3 Metaluminous granitoids	2-9
2.4.4 Late granites	2-10
2.5 REGIONAL STRUCTURE AND METAMORPHISM	2-11

CHAPTER 3: GEOLOGY AND DESCRIPTION OF GRANITOID ROCKS IN THE COMMITTEE BAY BELT	3-1
3.1 INTRODUCTION	3-1
3.2 GEOLOGY OF THE COMMITTEE BAY AREA	3-1
3.2.1 Introduction	3-1
3.2.2 Geological overview of the area.....	3-2
3.2 ASSEMBLAGES OF THE COMMITTEE BAY BELT.....	3-2
3.3.1 Walker Lake Intrusive Complex.....	3-2
<u>3.3.1.1 Geology of the Walker Lake intrusive complex</u>	3-2
<u>3.3.1.2 U-Pb geochronology</u>	3-4
3.3.2 Central Prince Albert Group.....	3-5
<u>3.3.2.1 Geology of the central Prince Albert group</u>	3-5
<u>3.3.2.2 U-Pb geochronology</u>	3-8
3.3.3 Northern Migmatite Sub-domain	3-9
<u>3.3.3.1 Geology of the northern migmatite sub-domain</u>	3-9
<u>3.3.3.2 U-Pb geochronology</u>	3-10
3.4 FIELD RELATIONSHIPS AND PETROGRAPHY OF THE PERALUMINOUS GRANITE SERIES	3-11
3.4.1 Introduction	3-11
3.4.2 Peraluminous leucogranite series	3-12
3.4.3 Peraluminous S-type granite series.....	3-13
3.5 SUMMARY.....	3-14
CHAPTER 4: LITHOGEOCHEMISTRY AND NEODYMIUM ISOTOPIC SIGNATURE OF THE COMMITTEE BAY PLUTONS.....	4-1
4.1 INTRODUCTION	4-1
4.2 GEOCHEMISTRY OF THE NEOARCHEAN GRANITOIDS	4-1
4.2.1 Major Elements	4-1
<u>4.2.1.1 Magma suites and alumina index</u>	4-3
4.2.2 Trace Elements	4-4
<u>4.2.2.1 Trace elements in the metaluminous granitoids</u>	4-5
4.2.3 Rare Earth Element Diagrams	4-6
4.2.4 Extended Element Diagrams	4-8
4.2.5 Sm and Nd Isotopes.....	4-10
4.3 GEOCHEMISTRY OF THE PERALUMINOUS GRANITE SERIES	4-11
4.3.1 Introduction	4-11
4.3.2 Major Elements	4-12
<u>4.3.2.1 Magma suites and alumina index</u>	4-12
4.3.3 Trace Elements	4-13
<u>4.3.3.1 Trace elements in peraluminous granitoids</u>	4-13
4.3.4 Rare Earth Element Diagrams	4-14

4.3.5 Extended Element Diagrams	4-15
4.3.6 Sm and Nd Isotopes	4-15
4.4 CHAPTER SUMMARY	4-16
CHAPTER 5: PETROGENESIS OF THE COMMITTEE BAY GRANITOIDS	5-1
5.1 INTRODUCTION	5-1
5.2 PETROGENESIS OF THE TONALITE SERIES	5-2
5.2.1 The role of fractional crystallization	5-2
5.2.2 Generation of parental magmas	5-3
5.3 PETROGENESIS OF THE GRANODIORITE/MONZOGRAHITE SERIES	5-4
5.3.1 The role of fractional crystallization	5-4
5.3.2 Generation of parental magmas	5-6
5.4 PETROGENESIS OF THE PERALUMINOUS SERIES	5-6
5.4.1 Generation of parental magmas	5-6
5.5 TECTONOMAGMATIC SUMMARY OF GRANITOID MAGMATISM WITHIN THE COMMITTEE BAY BELT	5-8
REFERENCES	
APPENDIX A: ANALYTICAL METHODS	A-1
A.1 GEOCHEMICAL SAMPLING AND PREPARATION	A-1
A.2 X-RAY FLUORESCENCE (XRF)	A-1
A.2.1 Fused-disc method for major element analysis	A-2
A.3 INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY (ICP-MS)	A-2
A.4 ISOTOPE DILUTION PROCEDURE FOR THE ANALYSIS OF SAMARIUM AND NEODYMIUM	A-3
APPENDIX B: PRIMITIVE MANTLE NORMALIZATION VALUES USED	B-1
APPENDIX C: PARTITION COEFFICIENTS USED	C-1

LIST OF TABLES

Table 3.1.	Summary of the field and petrological characteristics of the major granitoid divisions in the Committee Bay region	3-31
Table 4.1a.	Representative major element analyses for the Committee Bay granitoids	4-46
Table 4.1b.	Representative trace and REE analyses for the Committee Bay granitoids	4-50
Table 4.2.	Sm and Nd isotopic analyses from the Committee Bay granitoids	4-58

LIST OF FIGURES

Figure 1.1.	Location of Committee Bay belt study area (highlighted). Map also shows location of Archean supracrustal rocks throughout the western Churchill Province with emphasis on the Prince Albert group. <i>After Sandeman et al., 2001a.</i>	1-13
Figure 1.2.	Bedrock geology of the Committee Bay belt (NTS 56K, 56J(north), 56O(south) and 56P) after Sandeman <i>et al.</i> (2002), Skulski <i>et al.</i> (2002) and Skulski <i>et al.</i> (2003). Major structural elements from Sandeman <i>et al.</i> (2001), Sanborn-Barrie <i>et al.</i> (2002) and Sanborn-Barrie <i>et al.</i> (2003). <i>From Sandeman et al., 2004</i> ..	1-14
Figure 1.3.	Geological map of NTS 56J(north) and NTS 56O(south) showing locations of: granitoid units; lithological sub-domains; supracrustal sections within the Committee Bay belt (NHRB = north Hayes River belt, CHRB = central Hayes River belt, TP = Twin Peaks, TB = Three Bluffs, HW = Howling Wolf, HWLB = Howling Wolf Lake belt, KR = Kellett River). <i>After Skulski et al.</i> (2002a)....	1-15
Figure 2.1.	Lithotectonic zones and boundaries of northeastern North America. <i>After van Kranendonk et al.</i> (1993), Orrell <i>et al.</i> (1999) and Johnstone (2002).	2-14
Figure 2.2.	Field photo of rusty semi-pelitic rock intruded by granite dykes	2-15
Figure 2.3.	Supracrustal rocks of the Prince Albert group: a) field photo of komatiite; b) slab section of highly altered chloritic schist and; c) slab section of migmatitic paragneiss (upper portion is leucosome and lower portion is melanosome)	2-16
Figure 2.4.	Intrusive rocks of the Committee Bay region: a) slab section of peraluminous, equigranular monzogranite; b) slab section of metaluminous, K-feldspar augen texture granodiorite	2-17
Figure 2.5.	Simplified map of the northern migmatite sub-domain (NMS) east of the Arrowsmith River. Map also shows location of; southern metaluminous pluton (SMP); northern metaluminous pluton (NMP); peraluminous leucogranite series (PLGS) and; peraluminous classic “s-type” granite series (PSGS).....	2-18

Figure 3.1.	Monzogranitic unit intruding semi-pelitic rocks of the Committee Bay belt.....	3-16
Figure 3.2.	Photos of K-feldspar augen granodiorite unit: a) field photo of pink K-feldspar augen granodiorite; b) slab section of pink K-feldspar augen granodiorite and; c) field photo of white K-feldspar augen granodiorite.	3-17
Figure 3.3.	Photomicrographs of K-feldspar augen granodiorite (xpl); a) textural appearance of unit; b) blebby quartz and biotite defining the foliation of the rock; c) cross-hatch twinning within the feldspars and; d) epidote alteration around a feldspar megacryst.....	3-18
Figure 3.4.	Field photos of bio-bearing monzogranite: a) bio-bearing monzogranite dyke intruding bio±mag-bearing granodiorite unit and; b) bio-rich monzogranite intruding bio-bearing tonalitic gneiss.	3-19
Figure 3.5.	Photos of bio-bearing tonalite: a) field photo of bio-bearing tonalite; b) highly deformed bio-rich tonalitic gneiss and; c) slab section of bio-bearing tonalite.	3-20
Figure 3.6.	Photomicrographs of bio-bearing tonalite: a) bio-rich portion of sample (xpl); b) bio defining the foliation (ppl) and; c) textural appearance and mineralogy (xpl).	3-21
Figure 3.7.	Photos of hbl-bio-bearing quartz diorite: a) slab section of quartz diorite; b) photomicrograph (scale = 400 µm) showing quartz diorite mineralogy (ppl) and; c) photomicrograph (scale = 400 µm) showing quartz diorite mineralogy (xpl).	3-22
Figure 3.8.	Photos of bio±mag-bearing granodiorite: a) slab section of unit; b) photomicrograph (scale = 400µm) showing bio±mag-bearing granodiorite texture (xpl); c) mineral inclusions within cleavage planes of feldspar (xpl)(scale = 300µm) and; d) granophyric texture(scale = 200µm)	3-23
Figure 3.9.	Field photo of bio-bearing syenogranite (a) and bio-bearing monzogranite (b)	3-24
Figure 3.10	Photomicrographs of monzogranite: a) texture and mineralogy of unit (xpl) (scale = 400µm) and; b) myrmekitic texture (xpl).....	3-25
Figure 3.11.	Field photos of bio-musc-grt-bearing monzogranite: a) monzogranitic dykes cutting metasediments and; b) boudinaged bio-musc-grt-bearing monzogranite dyke cutting refractory iron-formation within the NMS	3-26
Figure 3.12.	Highly strained bio-bearing tonalite with interbedded semi-pelite found near the Arrowsmith River shear zone (hammer for scale).....	3-27

Figure 3.13.	Photos of bio-hbl-bearing tonalite: a) field appearance of unit; b) slab section of unit; c) textural appearance (ppl) (scale = 400 μ m) and; d) textural appearance (xpl) (scale = 400 μ m)	3-28
Figure 3.14.	Photos of PLGS: a) field photo of PLGS intruding metasediments; b) slab section of unit and; c) photomicrograph showing texture and mineralogy (xpl) (scale = 300 μ m)	3-29
Figure 3.15.	Photos of PSGS: a) slab section of PSGS; b) photomicrograph showing textures in feldspars (xpl) and; photomicrograph showing garnet with sillimanite inclusions.....	3-30
Figure 4.1.	QAP (quartz-alkali-feldspar-plagioclase) diagram for Committee Bay granitoids. Fields are from Streickheisen (1976)	4-19
Figure 4.2.	Harker diagrams showing major element variations within the Committee Bay granitoids	4-20
Figure 4.3.	Harker diagrams showing major element variations within the Committee Bay granitoids	4-21
Figure 4.4.	Total alkalis (Na ₂ O + K ₂ O) versus silica diagram. Alkaline versus sub-alkaline field boundary is from Irvine and Barager (1971).....	4-22
Figure 4.5.	Ternary AFM diagram for Committee Bay granitoids. FeO* was recalculated from total Fe using the method from LeMaitre (1976)	4-23
Figure 4.6.	K ₂ O versus silica diagram for Committee Bay granitoids. Field boundaries are from Peccerillo and Taylor (1976)	4-24
Figure 4.7.	Molecular Al ₂ O ₃ /(Na ₂ O + K ₂ O) versus Al ₂ O ₃ /(CaO +Na ₂ O +K ₂ O) diagram for Committee Bay granitoids. Field boundaries are from Manier and Piccoli (1989)	4-25
Figure 4.8.	Harker diagrams showing trace element compositions of the Committee Bay granitoids	4-26
Figure 4.9.	Harker diagrams showing trace element compositions of the Committee Bay granitoids	4-27
Figure 4.10.	Primitive mantle normalized REE diagram for metaluminous granitoids. Subdivisions are based on silica content: a) 61-63 wt. %; b) 64-66 wt. % and; c) 67-72 wt. %	4-28

Figure 4.10d.	Primitive mantle normalized REE diagram for metaluminous granitoids based on silica content <60 wt. %.	4-29
Figure 4.11.	Normalized extended REE diagram for metaluminous granitoids. Sub-divisions are based on silica content: a) 61-63 wt. %; b) 64-66 wt. % and; c) 67-72 wt. %	4-30
Figure 4.11d.	Normalized extended REE diagram for metaluminous granitoids based on silica content <60 wt. %.....	4-31
Figure 4.12.	Diagrams showing epsilon Nd values; a) epsilon Nd versus silica; b) epsilon Nd versus normalized (La/Yb) and; c) epsilon Nd versus normalized (La/Sm)	4-32
Figure 4.13.	QAP (quartz-alkali-feldspar-plagioclase) diagram for peraluminous Committee Bay granitoids. Fields are from Streickheisen (1976)	4-33
Figure 4.14.	Harker diagrams showing major element variations within the peraluminous Committee Bay granitoids	4-34
Figure 4.15.	Harker diagrams showing major element variations within the peraluminous Committee Bay granitoids	4-35
Figure 4.16.	Total alkalis ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) versus silica diagram for peraluminous granitoids. Alkaline versus sub-alkaline field boundary is from Irvine and Barager (1971).....	4-36
Figure 4.17.	Ternary AFM diagram for peraluminous Committee Bay granitoids. FeO^* was recalculated from total Fe using the method from LeMaitre (1976)	4-37
Figure 4.18.	K_2O versus silica diagram for peraluminous Committee Bay granitoids. Field boundaries are from Peccerillo and Taylor (1976)	4-38
Figure 4.19.	Molecular $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O})$ versus $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ diagram for peraluminous Committee Bay granitoids. Field boundaries are from Manier and Piccoli (1989)	4-39
Figure 4.20.	Harker diagrams showing trace element compositions of the peraluminous Committee Bay granitoids	4-40
Figure 4.21.	Harker diagrams showing trace element compositions of the peraluminous Committee Bay granitoids	4-41
Figure 4.22.	Primitive mantle normalized REE diagram for peraluminous granitoids.....	4-42
Figure 4.23.	Normalized extended REE diagram for peraluminous granitoids.....	4-43

Figure 4.24.	Epsilon Nd versus silica showing values of plagioclase-rich series (highlighted) in relation to K-feldspar-rich series	4-44
Figure 4.25.	Harker diagrams showing trace element compositions and difference in trends between the plagioclase-rich series and the K-feldspar-rich series	4-45
Figure 5.1.	a) normalized REE diagram showing increase in LREE fractionation with respect to increasing silica in the plagioclase-rich series; b) molecular $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O})$ versus $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ diagram for the plagioclase-rich series; c) 10-20% hornblende fractionation using 61-63 wt% silica average as starting material(dashed line) and; d) SiO_2 wt. % versus $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$	5-10
Figure 5.2.	a) extended REE diagram showing increased fractionation of units in the granodioritic/monzogranitic series with respect to increasing silica wt. %; b) REE diagram of silica end-members in the granodioritic/monzogranitic series; c) logarithmic plot of Ba versus Sr showing K-feldspar fractionation trend.....	5-11
Figure 5.3.	Epsilon Nd versus SiO_2 displaying similarities in epsilon Nd signature between granodioritic/monzogranitic series, PLGS, PSGS, and migmitites.	5-12
Figure 5.4.	a) REE diagram showing negative Eu anomalies in PSGS and flat Eu trends in PLGS and; b) extended REE diagram comparing/contrasting ranges in Th and P between PLGS, PSGS and metaluminous granodiorite.....	5-13
Figure 5.5.	Diagram showing $\epsilon\text{Nd}(t)$ versus age (Ga) for Committee Bay granitoids and komatiites. Depleted Mantle evolution curve is calculated from $\epsilon\text{Nd}(t) = 8.6 - 1.91(t)$ where (t) is age (DePaolo <i>et al.</i> , 1991). Komatiite values from Machattie (personal communication).	5-14
Figure 5.6.	Cartoon depicting the Late Archean evolution of the Committee Bay region; a) ca. 2.72 Ga development of late ultramafic volcanism and intermediate to felsic magmatism as a result of dehydration melting of amphibolitic source rocks; b) ca. 2.72-2.61 Ga plutonism during which some quartz dioritic and tonalitic melts are emplaced while others continue to assimilate older crust and evolve and; c) ca. 2.61-2.58 Ga crustal melting/migmatization of sediment package at low- to mid-crustal levels assimilating with previously formed melts creating metaluminous granitoids followed by peraluminous melt formation as the result of fast adiabatic uplift and decompression.....	5-15

LIST OF ABBREVIATIONS A:

A/CNK.....	Molecular $Al_2O_3/(CaO + Na_2O + K_2O)$
A/NK.....	Molecular $Al_2O_3/(Na_2O + K_2O)$
AFM.....	$Na_2O + K_2O$ (A) - FeO^* (F) - MgO (M)
Bio.....	Biotite
CHUR.....	Chondritic Uniform Reservoir
Gdr.....	Granodiorite
Hbl.....	Hornblende
Grt.....	Garnet
Sil.....	Silimanite
HFSE.....	High-field-strength elements
HREE.....	Heavy rare earth elements
Kd.....	Distribution coefficient
LFSE.....	Low-field-strength elements
LREE.....	Light rare earth elements
Md.....	Monzodiorite
Mgn.....	Monzogranite
MREE.....	Middle rare earth elements
Musc.....	Muscovite
QAP.....	Quartz-Alkali Feldspar-Plagioclase
QD.....	Quartz Diorite
PM.....	Primitive Mantle
ϵNd	Epsilon Neodymium

LIST OF ABBREVIATIONS B:

CPAG.....	central Prince Albert group sub-domain
CBb.....	Committee Bay belt
Kgn.....	Kuagnat gneiss complex
NMP.....	northern metaluminous pluton
NMS.....	northern migmatite sub-domain
KAGS.....	K-feldspar augen granodiorite series
ARsz.....	Arrowsmith River shear zone
BMGS.....	biotite-megacrystic granodiorite series
BTS.....	biotite tonalite series
HBTS.....	hornblende-biotite tonalite series
HBDS.....	hornblende-biotite quartz diorite series
HBTS.....	biotite monzogranite to syenogranite series
PLGS.....	peraluminous leucogranite series
PSGS.....	peraluminous S-type granite series
PAg.....	Prince Albert group
SMP.....	southern metaluminous pluton
THO.....	Trans-Hudson Orogen
WCP.....	western Churchill Province
WLIC.....	Walker Lake intrusive complex

CHAPTER 1: INTRODUCTION

1.1 Introduction:

The Rae domain of the western Churchill Province is comprised of voluminous, ca. 2600 Ma, commonly potassic granitoid bodies that intrude relatively thin packages of Archean supracrustal rocks. The supracrustal sequences define an approximately 1800 km-long, northeast linear trend and include rocks of the Murmac Bay group in northern Saskatchewan (Hartlaub *et al.*, 2001), the Woodburn Lake group (Davis and Zaleski, 1998; Zaleski *et al.*, 1999) and Prince Albert group (Sandeman *et al.*, 2001a, b; Skulski *et al.*, 2002a, b) in Mainland Nunavut, and the Mary River Group on Baffin Island (Bethune and Scammell, 1997) (Figure 1.1). The present study focuses on the geology, geochemistry, isotopic composition and geochronology of the metaplutonic rocks surrounding the supracrustal sequence comprising the Prince Albert group, with the goal of outlining their compositional variations and constraining the tectonic setting of their emplacement.

Granitoid plutonism is closely linked, both spatially and temporally, to orogenic processes and hence these magmas typically occur in modern orogenic zones such as active volcanic arc and continental collisional settings. The formation of granitoids in collisional settings can be attributed to thermal/deformation-induced disturbances in the crust and lithospheric mantle, perhaps resulting from gravitational collapse and subsequent extension following lithospheric thickening (Patino-Douce, 1999). However, development of volcanic arcs and their associated granitoids typically require a significant contribution from the mantle. Differentiating between the distinct clans of granitoids and understanding the processes resulting in granitoid plutonism are key

features in defining the magmatic record of an orogenic zone and attempting to assign a valid geodynamic model for a region.

This contribution provides details on the compositional variations within a variety of metaplutonic rocks that intrude the Prince Albert group of mainland Nunavut with the intent of constraining the tectonic setting of this region during the late Archean.

1.2 Setting of the Area

The northern migmatite sub-domain (NMS) of the Committee Bay belt, Rae structural province, Nunavut encompasses part of the southern portion of the 1:250 000-scale NTS 56 O map sheet within the Walker Lake-Arrowsmith River area (Figure 1.2). The area is the northernmost of three major lithotectonic divisions within the belt that also include the central Prince Albert group (CPAG) and the Walker Lake intrusive complex (WLIC) (Figure 1.3). The NMS is comprised of supracrustal rocks of the upper Prince Albert group (Sandeman *et al.*, 2001b, Skulski *et al.*, 2002)) intruded by suites of both peraluminous and metaluminous granitoids. The domain lies north of the Arrowsmith River strand of the Committee Bay belt and is separated from the main supracrustal belt by the Arrowsmith River shear zone (ARSZ) (Skulski *et al.*, 2002; Sanborn-Barrie *et al.*, 2002).

Previous mapping in the Committee Bay belt has been conducted on a number of scales. Preliminary reconnaissance mapping conducted southwest of Committee Bay (Heywood 1961: 1:500 000 scale) roughly delineated the extent of supracrustal versus granitoid rocks. Mapping in the Laughland Lake (NTS 56 K) and the northern half of the Walker Lake (NTS 56 J) areas (Schau, 1982) created subdivisions within both the Prince

Albert group supracrustal sequence and distinct granitoid units enclosing the belt. Later mineral assessment reports issued by the Geological Survey of Canada (Jefferson and Schau, 1992; Chandler *et al.*, 1993) incorporated local, detailed mapping in conjunction with aerial reconnaissance and archival data compilation (Sandeman *et al.*, 2001a).

Mapping in the NMS was first carried out by the Committee Bay Targeted Geoscience Initiative Project team during the summer of 2001 with follow-up mapping during the summer of 2002. This contribution describes regional and detailed mapping within the Walker Lake-Arrowsmith River area conducted during the summers of 2001 and 2002. This study will also refer to areas mapped on a broader scale that covered three 1:250,000 scale sheets encompassing the entire Committee Bay belt (Figure 1.2). Mapping in this area was conducted during three summers from 2000-2002 under the Committee Bay Integrated Geoscience Project, a collaboration between the Canada-Nunavut Geoscience Office and the Geological Survey of Canada and funded in part through Targeted Geoscience Initiative I.

1.3 Research Goals

This study examines the nature and evolution of Neoarchean plutonic activity within the NMS and attempts to determine its relationship with the plutonism identified within the CPAG and WLIC (Figure 1.3). Based on field observations and lithogeochemical data, the majority of plutons in the Committee Bay belt are metaluminous intrusions with less voluminous peraluminous granitic plutonism exposed predominantly in the NMS, an area dominantly underlain by migmatitic metasedimentary rocks. Peraluminous granitoids are typically sub-divided into classic “S-type” and two-

mica clans. The former are considered to represent the H₂O-undersaturated, low-pressure anatectic products of aluminous crustal protoliths whereas the latter likely formed under H₂O-saturated and plausible higher pressure (Clemens and Wall, 1981; White and Chappell, 1983; White and Chappell, 1988; Patino-Douce, 1999). The role of mafic magmas in the production of peraluminous granitoids is a topic of significant debate, but many authors now consider that classic “S-type” granitoids require significant mantle input into their petrogenesis (Patino-Douce, 2001; Clemens, 2002). Field evidence suggests that the peraluminous granitoids exposed within the NMS are potentially the products of anatectic melt segregation triggered by the intrusion of metaluminous magmas into a thick package of sedimentary rocks of semi-pelitic to pelitic composition. These sedimentary rocks, likely associated with the upper Prince Albert group, were hydrothermally fluxed and possibly partially melted at shallow- to mid-crustal levels.

This study also focuses on the results of detailed geological mapping, lithogeochemical, isotopic and geochronological investigations of a wide range of metaplutonic rocks exposed in the Committee Bay area. The overall goals of the study are to characterize the Committee Bay plutonic rocks in order to examine their petrogenesis and to propose a geotectonic model for their formation. In particular the investigation closely details the petrology and evolutionary history of the plutonic rocks exposed in the northern migmatite sub-domain in order to clarify their compositional and petrogenetic distinctions with granitoid units exposed in the southeastward lying CPAG and WLIC sub-domains.

The main components of this portion of the study includes:

- a) Field observations and petrographic descriptions of the metaplutonic rocks

throughout the region in order to adequately describe the nature and distribution of the constituent units. This includes a detailed geologic map of the area.

- b) Lithogeochemical (major and trace elements) and isotopic (Sm-Nd) analyses of the intrusive rocks to define variations within, and between, units and evaluation of the geochemical constraints on the formation of these rocks.
- c) A discussion and summary on available geochronological data to provide information on the timing of plutonism in the area.
- d) A geological synthesis that assembles all of the diverse observations in order to construct a tectonic evolutionary model of plutonism during the interval 2.72-2.58 Ga in the Committee Bay area of mainland Nunavut.

1.4 Methodology

1.4.1 Introduction

The main goal of this thesis is to understand the origin of Neoarchean granitoids, and to determine their role in Neoarchean tectonism within the western Churchill Province. To accomplish this several laboratory methods were applied to samples from the study area. Data collected includes major and trace element geochemistry and Sm-Nd radiogenic isotopic analyses. The following is a brief discussion of the use and applicability of each of these methods.

1.4.2 Major and Trace Element Geochemistry

1.4.2.1 Introduction

Major and trace element geochemistry provide insight into the petrological and petrogenetic magmatic history of plutonic rocks. The chemical composition and mineralogy of the parental source regions exert considerable control over the chemistry of magmatic rocks (Rollinson, 1993).

This study evaluated the major element, trace element and rare-earth-element geochemistry of the Neoarchean granitoid suites. These analyses were performed in order to identify petrogenetic controls on the source region of igneous precursor of these rocks including any likely crustal contaminants.

The whole-rock geochemical analyses were carried out at Activation Laboratories and the University of Ottawa. The major element analyses obtained at University of Ottawa were analyzed by X-ray fluorescence spectrophotometry (XRF) fused glass discs using a 3:1 flux to sample ratio. The majority of the major element chemistry was completed at Activation Laboratories (Ancaster, Ontario) using lithium metaborate/tetraborate fusion followed by inductively-coupled plasma emission spectrometry (ICP-ES). Trace elements (including Rb, Sr, Zr, Pb, Nb and Ba) were analyzed by inductively-coupled plasma mass spectrometry (ICP-MS) using the sodium peroxide (Na_2O_2) sinter preparation method. Analytical details (sampling protocol, elements analysed, and analytical method) are given in Appendix A.

1.4.2.2 Discrimination diagrams

Major and trace elements were first plotted on discrimination diagrams to identify geochemical affinities. Plots used in this thesis include: Harker diagrams, the AFM plot and total alkalis versus silica of Irvine and Barager (1971), and A/NK versus A/CNK

from Maniar and Piccoli (1989). These plots are useful for rock classification but not all trends on the discrimination diagrams are meaningful (Rollinson, 1993).

The Quartz-Alkali Feldspar-Plagioclase and Anorthosite-Albite-Orthoclase diagrams display composition variations within the granitoid suite (Streckeisen, 1976). The AFM $\{\text{Na}_2\text{O} + \text{K}_2\text{O} (\text{A}) - \text{FeO}^* (\text{F}) - \text{MgO} (\text{M})\}$ diagram and the cation plot display calc-alkaline vs. tholeiitic trends in igneous rocks with less emphasis placed on the AFM plot due to inclusion of mobile elements affected by alteration.

1.4.2.3 Bivariant diagrams

Fractionation trends and magmatic relationships of the Neoarchean granitoids are displayed in Harker diagrams. These diagrams use SiO_2 vs. major elements, trace elements and trace element ratios and show chemical distinctions between the composition units.

As SiO_2 is the most abundant oxide in each of the samples, the Harker diagram can indicate false trends based on silica. Potential false trends include: 1) negative trends that reflect an increase in silica relative to other minerals that are not a real fractionation trends; 2) deceptive correlations and; 3) reduced scatter as SiO_2 increases. These limitations are generally outweighed by the ability of the diagrams to identify broad-scale chemical trends with increasing magma evolution.

1.4.2.4 Normalized rare-earth element and multi-element plots

Trace elements are more capable of discrimination between petrogenetic processes than major elements, and thus are useful indicators of the history of a magmatic

suite. This is because distribution of trace elements in the crust can be mathematically modeled and ultimately utilised to identify geological processes (Rollinson, 1993).

This study used primitive mantle normalized rare-earth element (REE) diagrams and multi-element diagrams to identify and compare trace element signatures within the Neoarchean granitoids. The REE elements are useful due to their similar chemical behavior and low mobility during low-grade alteration. The REE elements can also be expressed as a degree of fractionation, being the concentration of primitive mantle-normalized light REE ratio to heavy REE $(La/Yb)_N$, in addition to other primitive mantle normalized diagrams. The REE element pattern of an igneous rock is fundamentally controlled by the REE chemistry of its source and by the crystal-melt equilibria, through its magmatic evolution (Rollinson, 1993).

Multi-element diagrams are based on the grouping of elements that are incompatible with respect to typical mantle mineralogy. Specific element depletions or enrichments can characterize a specific tectonic environment. For example, Nb-Ta depletion, relative to the light REE, is characteristic of a subduction-zone component in the source region (Rollinson, 1993), and the lower continental crust is characterized by Th-U depletion, a feature thought to reflect the loss of these elements during granulite grade metamorphism.

Multi-element diagrams allow for discrimination between tectonic environments based on comparison with modern analogues. The greater contrast in element behavior allows for the possibility of enhanced spikes than do the REE diagrams. The potential similarities and differences between modern environments and Neoarchean environments are important factors in this study for understanding the tectonic processes at work during

the evolution of the region. These diagrams are also key in identifying characteristics of a source region or crustal contaminant.

1.4.3 Radiogenic Isotopes (Sm-Nd)

Radiogenic isotopes are capable of providing valuable insights into the petrogenetic history of magmatic rocks. Isotopic data can also constrain the tectonic development of a region by highlighting the relationship between crust-mantle processes, crustal contamination and basement influences (DePaolo, 1988).

Radiogenic isotopes can help highlight sources of magmas and determine whether they result from mantle melting or if they are the result of anatexis of older rocks due to high-grade metamorphism. Isotope data can also shed light on the overall geologic history of a terrane by dating the sequence of magmatic events.

The Sm-Nd analyses were carried out on a thermal-ionization mass spectrometer (TIMS) at Carleton University.

The Sm-Nd isotopic system is a useful petrogenetic tool for identifying the sources from which magmas formed and as a method of identifying crustal contaminants (DePaolo, 1988). Like the Sr and Pb isotope systems, the premise of this system is that the parent isotope (^{147}Sm) decays to a daughter isotope (^{143}Nd); however, the Sm-Nd system is much more robust than Sr and Pb isotope systems because Sm-Nd are more resistant to mobilization due to secondary processes such as metamorphism and alteration (DePaolo, 1988; Rollinson, 1993). Evidence exists, however, that indicates some fractionation of Sm from Nd occurs during high-grade (amphibolite to granulite grade) metamorphism (Collerson, 1989).

Bulk Earth values for the Sm-Nd system are believed to be represented by chondritic meteorites, which are referred to as the “chondritic uniform reservoir” (CHUR) (DePaolo and Wasserburg, 1976; DePaolo, 1988). The Sm-Nd ratios of crust and mantle reservoirs were subsequently fractionated during presumed widespread partial melting of the bulk earth (primitive mantle) to form the crust and depleted mantle reservoirs (DePaolo, 1988). The Nd isotopic composition of each reservoir evolves as a function of their Sm/Nd ratios due to the radioactive decay of ^{147}Sm to ^{143}Nd (Rollinson, 1993; and DePaolo, 1988).

Sm and Nd are both light rare earth elements and almost identical in chemical behaviour, with an exception that Nd has a slightly larger ionic radius. This difference results in the preferential partitioning of Nd into the melt phase during partial melting of the upper mantle (DePaolo, 1988). This preferential partitioning produces a residual (depleted) mantle with higher Sm/Nd ratios than that of CHUR and the continental crust, which formed from the resulting melt. Thus over time, the crustal reservoir is enriched in LREE and has a Sm/Nd ratio lower than CHUR (DePaolo, 1988). Although the geochemical dynamics of crust and mantle reservoirs are undoubtedly more complex, this model does provide a method for describing and interpreting the Nd isotopic variations of the crust-mantle evolution (DePaolo, 1988).

The range of $^{147}\text{Sm}/^{143}\text{Nd}$ for terrestrial rocks is rather small, from 0.1 to 0.3 (DePaolo, 1988). In combination with the long half-life of ^{147}Sm (1.06×10^{11} years), this results in a relatively narrow range of $^{143}\text{Nd}/^{144}\text{Nd}$ values in rocks. It has therefore become common to describe the $^{143}\text{Nd}/^{144}\text{Nd}$ ratios using epsilon values given by ϵNd (DePaolo, 1988), using the equation:

$$\epsilon\text{Nd}_{(t)} = \left\{ \left[\left(\frac{{}^{143}\text{Nd}}{{}^{144}\text{Nd}}_{\text{rock}, t} \right) / \left(\frac{{}^{143}\text{Nd}}{{}^{144}\text{Nd}}_{\text{CHUR}, t} \right) - 1 \right] \right\} * 10^4$$

where ${}^{143}\text{Nd}/{}^{144}\text{Nd}_{\text{rock}, t}$ is the isotopic ratio of the rock at time t , and ${}^{143}\text{Nd}/{}^{144}\text{Nd}_{\text{CHUR}, t}$ is the isotopic ratio of CHUR at time t . The use of this notation allows for the methodical presentation and comparison of Nd isotopes relative to CHUR. Thus, the ϵNd values are dependant on the CHUR model and the age of the rock needs to be known.

Based on this convention, ϵNd values for CHUR are always 0, independent of age (DePaolo, 1988). In general, rocks derived from a LREE-depleted source (i.e. depleted mantle or other mantle reservoir) will have $\epsilon\text{Nd} > 0$; while rocks derived from a LREE enriched source (continental crust or enriched mantle) or rocks effected by crustal contamination will have $\epsilon\text{Nd} < 0$. Rocks with ϵNd close to 0 could have been derived from a CHUR-like source (primitive mantle) or magmas that represent a mixture of depleted and enriched sources.

Attempting to distinguish between depleted and enriched sources for the Committee Bay granitoids using Nd isotopes is particularly appropriate. If the crust in the Committee Bay area was formed >100 Ma prior to the production of the constituent granitoids, then the Nd isotopic composition of the two likely end-member sources of the granitoid suite, i.e. slightly more evolved Archean crust versus depleted mantle, would have had resolvable values in the Neoarchean. Thus, the Sm-Nd isotope system may potentially provide critical insight into the plutonic history of the area.

1.5 Organization of the Thesis

Chapter 2 summarizes the previous geological and geochronological information available on the western Churchill Province. Information regarding the tectonic

evolution of the western Churchill Province is discussed in an effort to better understand Committee Bay geology and the events that may have effected the region. The chapter also includes a discussion of the various rock suites and their location with respect to the study area.

Chapter 3 takes a closer look at the petrography of the granitoid units intruding the Committee Bay belt and surrounding area. This chapter lists and discusses modal mineralogy within the rocks and how it relates to their compositions. Field characteristics, location of the units, their volume within the Committee Bay area, and their cross-cutting relationships are discussed. This chapter will develop a geological framework and be the basis for a petrographic interpretation of the study area.

Chapter 4 is a detailed description of the lithogeochemistry of the individual granitoid units. Major, trace and REE elements are presented in a series of geochemical plots that aid in further lithological classification of the rocks and a large part of the basis for the proposal of a tecto-magmatic environment within which the granitoids formed, evolved and were eventually emplaced.

Chapter 5 is a summary of conclusions from the previous chapters and is a compilation of the results of the thesis.

Figure 1.1. Location of Committee Bay belt study area (highlighted). Map also shows location of Archean supracrustal rocks throughout the western Churchill Province with emphasis on the Prince Albert group. *After Sandeman et al., 2001a.*

Figure 1.2. Bedrock geology of the Committee Bay belt (NTS 56K, 56J(north), 56O(south) and 56P) after Sandeman et al. (2002), Skuiski et al. (2002) and Skuiski et al. (2003). Major structural elements from Sandeman et al. (2001), Sanborn-Barne et al. (2002) and Sanborn-Barne et al. (2003). From Sandeman et al., 2004.

Figure 1.3. Geological map of NTS 56J(north) and NTS 56O(south) showing locations of: granitoid units; lithological sub-domains; supracrustal sections within the Committee Bay belt (NHRB = north Hayes River belt, CHRB = central Hayes River belt, TP = Twin Peaks, TB = Three Bluffs, HW = Howling Wolf, HWLB = Howling Wolf Lake belt, KR = Kellett River). *After Skulski et al. (2002a).*

CHAPTER 2: REGIONAL GEOLOGY

2.1 Introduction

The western Churchill Province is an Archean craton flanked by Paleoproterozoic orogenic belts. The western Churchill Province is subdivided into the Rae and Hearne domains along the northeast-trending Snowbird Tectonic Zone (STZ) (Figure 1.1), a late Archean structure that has experienced significant reworking during the Paleoproterozoic (Tella *et al.*, 1994; Sanborn-Barrie *et al.*, 2001; Mills, 2001; Baldwin *et al.*, 2003). The STZ has been identified on the basis of geophysical data and is represented geologically by discrete mylonitic zones and corridors of heterogeneous low-grade cataclasites intruded by late Archean granitoids (Aspler *et al.*, 1999).

2.2 Geology and tectonic setting of the Rae Domain

North of the STZ, extending more than 2000 km northeast from northern Saskatchewan towards Hudson Bay is the Rae domain of the western Churchill Province. The Rae domain is characterized by northeast-trending greenschist- to mid-amphibolite-facies supracrustal belts and rare associated intrusive rocks, widely intruded by ca. 2.6 Ga granitoid complexes (Frisch, 1982). These supracrustal belts include; the Murmac Bay group in northern Saskatchewan (Hartlaub *et al.*, 2001); the Woodburn Lake and Whitehills-Tehk groups, approximately 300 km southwest of the study area (Zaleski *et al.*, 1999); the Prince Albert group (Sandeman *et al.*, 2001a, b; Hyde, 2002; Johnstone *et al.*, 2002; MacHattie, 2002; Sanborn-Barrie *et al.*, 2002; Skulski *et al.*, 2002; Deyell and Sherlock, 2003; Sanborn-Barrie *et al.*, 2003); and the Mary River group located on Baffin Island (Bethune and Scammell, 1997). The Prince Albert group in the Committee Bay

area is identified as a corridor of supracrustal rocks characterized by a komatiite-quartzite association that also contains pelites, psammites, conglomerates, iron formation and rare mafic-felsic extrusives (Skulski *et al.*, 2003).

The present study is the first detailed geochemical and isotopic study of plutonic rocks associated with the Committee Bay supracrustal belt. Previous mapping in the area conducted by Heywood (1961, 1:500,000) and Schau (1982; 1:250,000) broadly constrained the regional geology and identified the northeast trending regional fabric defined by the Prince Albert group. The Walker Lake shear zone, an east-trending shear zone found mainly in the CPAG of the Committee Bay belt, was first identified during gold exploration by Apex Geosciences Ltd in 1992 (Dufresne and Williamson, 1997; Sandeman *et al.*, 2001a,b,c; Skulski *et al.*, 2002a). Additional data from the area was collected by the Committee Bay Integrated Geoscience Project.

The Rae domain is the northernmost portion of the western Churchill Province (Figure 2.1). To the west, the Rae domain is separated from the Slave craton by the Thelon Tectonic zone, a magmatic belt comprised of granulite facies ortho- and paragneisses, and younger granitoid plutons (Thompson and Henderson, 1983; Van Breeman *et al.*, 1987a, b; Henderson *et al.*, 1990; Hanmer *et al.*, 1992). The Thelon Tectonic zone is inferred to have formed ca. 2.01-1.91 Ga as a result of collisional deformation resulting from interaction between the Slave Province and Rae domain.

On Baffin Island, to the southeast of the Rae domain, lies the Cumberland batholithic complex that ranges in age from ca. 1950-1854 Ma (Jackson *et al.*, 1990; Pidgeon and Howie, 1975). The area is interpreted to represent the magmatic products resulting from the onset of Paleoproterozoic subduction of the Superior beneath the

leading edge of the Rae craton. North of the Cumberland batholith is the Foxe fold belt which is interpreted to be the northern margin of the Trans-Hudson Orogen (Corrigan *et al.*, 2001). To the east is the Archean Disko terrane and to the south the Dorset belt (Van Kranendonk *et al.*, 1993).

South of the Rae domain, and the southernmost portion of the western Churchill Province, is the Hearne domain. This area of the western Churchill Province is sutured to the Superior Province via the Paleoproterozoic Trans-Hudson orogen. This orogenic belt extends from northern Labrador south through western Ontario and Manitoba and through the central United States. The youngest known age of subduction-related plutonism is ca. 1820 Ma, constraining the maximum timing of terminal collision (Van Kranendonk *et al.*, 1993; Machado *et al.*, 1999; Orrell *et al.*, 1999; St-Onge *et al.*, 1999; Zwanzig, 1999).

2.3 Geology of the Prince Albert group

The Committee Bay belt is characterized by northeast-trending strands of Archean supracrustal rocks of the Prince Albert group (Figure 1.2). These are flanked and intruded to the northwest and southeast by peraluminous and metaluminous granitoids respectively. The Archean supracrustal assemblage extends across mainland Nunavut, through Committee Bay to Melville Peninsula. Within this area the Prince Albert group consists mainly of metamorphosed semi-pelite, psammite, quartzite, pelite, with lesser amounts of iron-formation, komatiite, and rare basaltic to intermediate volcanic rocks and felsic tuffs (Sandeman *et al.*, 2001b; Skulski *et al.*, 2002; Johnstone *et al.*, 2002; MacHattie, 2002; Sanborn-Barrie *et al.*, 2002).

The Committee Bay belt in the Walker Lake-Arrowsmith River area is intruded by granitoids ranging from diorite to abundant granodiorite and monzogranite. The supracrustal rocks and their associated intrusions are divided into three broad laterally continuous, lithological associations (Skulski, *et al.*, 2003); a) a central Prince Albert group (CPAG), characterized by the northeast-trending Prince Albert group with rare synvolcanic tonalities and voluminous ca. 2.6 Ga intrusive rocks; b) the Walker Lake intrusive complex (WLIC) comprising abundant ca. 2.6 Ga potassium-feldspar megacrystic to augen granodiorite to monzogranite (Sandeman *et al.*, 2001b); c) and a northern migmatite sub-domain (NMS) that is characterized by the presence of upper-amphibolite facies migmatitic paragneisses, metatexite, diatexite and meta-peraluminous, ca. 2.58 Ga, intrusive rocks (Skulski *et al.*, 2002a) that extends westward and was interpreted to be part of the Kuagnat Complex (Schau, 1982).

The CPAG consists primarily of three narrow belts of northeast-trending greenschist- to mid-amphibolite-facies Prince Albert group volcano-sedimentary successions (Skulski *et al.*, 2002a) intruded and plutonically inflated by a wide range of plutonic rocks. These supracrustal sequences include the: 1) northern Hayes River belt; 2) central Hayes River belt and; 3) Howling Wolf Lake belt (Figure 1.3).

The northern Hayes River belt and central Hayes River belt are located in the middle-western portion of the NTS 56 J/56 O map sheet (Figure 1.3). Both belts are basalt and komatiite-bearing volcanic successions with the exposed stratigraphy reaching up to 5 km thick. The northern Hayes River belt comprises amphibolite-facies, massive to pillow basalt overlain by komatiite, pelite and a thin upper basalt unit. The komatiite

sequence contains younging indicators that suggest an overall northward younging direction.

The central Hayes River belt has a stratigraphy very similar to the northern Hayes River belt with the only difference being that the komatiites and pelitic sediments are interlayered. Both the northern and central Hayes River belts are cut by gabbro sills, quartz diorite dykes, and felsic plagioclase porphyritic sills.

Extending across the width of the map area is the Howling Wolf Lake belt. This is a sedimentary rock-dominated supracrustal strand that is up to 7 km in width (Figure 1.3). The lower portion of the sequence is composed of komatiitic flows that contain thin layers of quartz-sericite schist between individual flows. Further up the sequence, komatiitic flows are locally interlayered with mafic volcanic flows or alternatively overlain by metawacke-semipelite, as seen near the Kellett River and Twin Peaks areas (Figure 1.3). Within the metawacke unit is a layer of oxide-facies iron-formation. Overlying the metawacke is a prominent quartzite unit. This unit is then overlain by dacitic lapilli tuff which is capped by a second section of deformed komatiite and siliciclastic sedimentary rocks.

2.3.1 Metasedimentary siliciclastic rocks

The most abundant rock type in the Prince Albert group is siliciclastic metasedimentary rocks. These are dominated by fine-grained biotite psammite and semipelite (biotite±muscovite±garnet) (Figure 2.2). These rocks occur throughout the Prince Albert group, but generally form recessive, low rubbly outcrop, rubble and dispersed rubble (Sandeman *et al.*, 2001a). Interlayered with these units are metre- to decimeter-

scale pelitic units, that commonly contain aluminosilicate minerals such as andalusite and sillimanite, and lesser amounts of arenitic and volcanoclastic units. Although bedding is commonly preserved in the psammites, younging indicators are typically rare and ambiguous owing to subsequent deformation and leucosome melt pod segregation. Both silicate facies and oxide facies iron-formation are also identified in the Prince Albert group. Silicate facies iron-formation is characterized by the presence of garnet and grunerite whereas oxide facies iron formation contain chert and magnetite, both of which are locally associated with sulphide mineralization. Sulphides are most commonly pyrrhotite and pyrite with minor chalcopyrite and arsenopyrite. The iron formations range from 1 to 50 metres thick and are usually very heterogeneously deformed. Quartz arenite horizons are typically high weathering, and are locally up to several hundred metres thick. The quartz arenite units rarely contain aluminous minerals such as muscovite and fuchsite. U-Pb detrital zircon ages have been obtained from a thick quartzite unit north of Walker Lake that indicate a maximum depositional age of 2722 Ma (Skulski *et al.*, 2002a,b; Skulski and Rayner, unpublished data).

2.3.2 Metavolcanic rocks

The dominant metavolcanic rock in the Prince Albert group is komatiite (Figure 2.3a). Komatiites are observed throughout the supracrustal belt as thick ($\leq 200\text{m}$) ridges consisting of numerous individual flows, many of which preserve spectacular spinifex textures and cumulate zones (Sandeman *et al.*, 2001a; MacHattie, 2002). Flows have locally been hydrothermally altered, resulting in a typical mineral assemblage of secondary serpentine + chlorite + tremolite/actinolite + magnetite (MacHattie, 2002).

Younging directions can typically be obtained in the komatiitic flows through establishing the B-zone, characterized by cumulate olivine grains, from the overlying A-zone which is composed of bladed spinifex. Way-up can also be determined through determining the branching direction of the spinifex blades (Fowler, *personal comm.*).

Basaltic rocks are significantly less abundant than ultramafic rocks in the Prince Albert group and are typically highly altered, chloritic schists (Figure 2.3b). Pillows are rarely preserved and younging indicators are usually destroyed by subsequent deformation. U-Pb zircon dating has constrained the timing of mafic volcanism to ca. 2732 Ma on the basis of zircons extracted from a felsic lapilli tuff, interlayered with mafic volcanic rocks (Skulski *et al.*, 2003).

2.3.3 Migmatitic rocks

North of the main Prince Albert group supracrustal sequence, and bounded to the south by the Arrowsmith River shear zone in NTS 56 O, lies a package of metasedimentary rocks composed of migmatite, paragneiss, diatexite and metatexite (Figure 2.3c). Although these units are very granitic in appearance they are identified as metasedimentary rocks due to their high proportion of residual mineral assemblage biotite-plagioclase-quartz $\pm$ garnet $\pm$ sillimanite. Diatexite bodies are commonly potassium-feldspar phyric to megacrystic augen monzogranite and syenogranite. This unit contains melanocratic layers that account for 10-25% of the rock and consist of muscovite+sillimanite+garnet. Metatexite bodies are metasedimentary-dominated with biotite+sillimanite+plagioclase+quartz+garnet $\pm$ cordierite and likely had a pelitic

protolith. The metatexite also contains leucocratic layers that account for 30-50% of the rock and consist of dominantly plagioclase and quartz.

These units are interpreted to be correlative with the Kuagnat gneiss complex (Schau, 1982, Sandeman *et al.*, 2001a) described to the west and southwest. The rocks of the Kuagnat gneiss complex are considered to represent deeper structural/metamorphic levels of the Prince Albert group stratigraphic sequence and represent a composite package of granitoid sheets and interlayered metasedimentary rocks intruded and metamorphosed at shallow to mid-crustal levels (Sandeman *et al.*, 2001a).

2.4 Intrusive Rocks

2.4.1 Walker Lake intrusive complex (WLIC)

South and east of the Prince Albert group supracrustal belt, within the southeastern portions of the study area, lies the Walker Lake intrusive complex. The WLIC is composed of a complex, polydeformed collage of foliated and locally gneissic plutonic units ranging from rare gabbro and tonalite through abundant, granodiorite, and monzogranite (Sandeman *et al.*, 2001a; Skulski *et al.*, 2002 & 2003) (Figure 1.2).

Apophyses of the intrusions are locally observed to cross-cut the supracrustal belt as dykelets and veins. The intrusive units are generally moderately foliated and strongly lineated with fabrics similar to those observed in the Prince Albert group units to the north. Accessory minerals include biotite±hornblende±magnetite±titanite±allanite.

2.4.2 Peraluminous granitoids

The NMS hosts scattered quartzo-feldspathic plutons and dykes that are dominantly granodiorite to monzogranite in composition and contain the assemblage biotite±muscovite±garnet±sillimanite±cordierite (Figure 2.4a). These units were rarely identified in the Committee Bay area and occur almost exclusively in the NMS (Figure 2.5). The rocks are identified as small intrusive bodies that ranged from 50-500 m long and 50-100 m wide. L-S fabrics in the peraluminous units are consistent with fabrics observed in the PAG, with the S-fabric typically outlined by biotite-rich schleiren.

The peraluminous intrusives of the NMS are typically observed in close proximity with the more abundant metaluminous intrusions in the area. Attempts to determine the age of crystallization of the peraluminous granites yielded discordant results with ages ranging from 2.28-2.68 Ga. A metaluminous granodioritic body in close proximity with the peraluminous granites was analyzed successfully and yielded a U-Pb monazite crystallization age of ca. 2.58 Ga (Carson, *personal communication.*).

2.4.3 Metaluminous granitoids

Metaluminous rocks are dominantly strongly foliated tonalite to granodiorite, commonly with a potassium-feldspar augen texture (Figure 2.4b). Accessory minerals include biotite, hornblende, magnetite, fluorite, titanite and allanite. The metaluminous intrusive rocks contain fabrics comparable to those measured in the CPAG with biotite defining the foliation and quartz grains defining the linear fabrics. Contact relationships between the metaluminous rocks and the CPAG are locally observed and xenoliths of pelite and semipelite occur within the margins of the granitoid.

Plutonism within the region is divided into two age brackets based on timing of crystallization. Tonalitic rocks crystallized at 2718 ± 2 Ma and are interpreted to be synmagmatic with intermediate tuffs of the Prince Albert group that have been dated at 2711 ± 3 Ma (Sanborn-Barrie and Davis, *unpublished data*). The intermediate tuffs are interlayered with mafic and ultramafic volcanic rocks, therefore, indicating that the timing of tonalitic plutonism coincides with mafic and ultramafic volcanism. The tonalites are the oldest plutonic unit in the Committee Bay region. A second magmatic event resulted in the formation of the granodioritic to monzogranitic plutons throughout the region. U-Pb SHRIMP analysis of zircons from these units yielded Neoproterozoic crystallization ages in the range 2.61-2.58 Ga.

2.4.4 Late granites

Intrusive rocks throughout the Committee Bay area are cut by a late phase of variably foliated, fine- to medium-grained monzogranite that contains biotite±magnetite±fluorite and locally is potassium-feldspar-phyrlic (Sandeman *et al.*, 2001a). These monzogranites form sheet-like bodies with massive, equigranular interiors and sheaths with country-rock inclusions. One of these has been dated by SHRIMP U-Pb method on zircon (east of Laughlan Lake) at 1831 ± 5 Ma (Skulski *et al.*, 2002). These rocks are petrologically similar to a suite of intrusions found near Wager Bay (LeCheminant *et al.*, 1987). Similar granitoid rocks found at other locations throughout the western Churchill Province have crystallization ages in the range 1830-1810 Ma (Peterson and van Breeman, 1999). These are the so-called “Hudson granitoids”.

2.5 Regional Structure and Metamorphism

The geology within map sheets NTS 56J north and NTS 56O south is some of the most structurally diverse of the region. The boundary between the WLIC and CPAG hosts an E-W trending sigmoidal-shaped corridor of sheared mylonitic rocks (Figure 1.3). This corridor termed the Walker Lake shear zone, is a dextral shear zone that has undergone up to five generations of deformation (Johnstone, 2002). A minimum age of 2716 ± 3 Ma has been determined on a tonalitic dyke that cross-cuts the zone therefore constraining the development of a D_{1a} prior to this age. D_{1b} in the Committee Bay area is estimated to have occurred ca. 2608 Ma. The $D_{2(a+b)}$ events are linked to regional shortening, ca. 1817 ± 3 Ma, and coincide with the terminal collision of the western Churchill Province with the Superior. D_3 occurred during crustal doming within the Paleoproterozoic and coincides with major shearing in the area that occurred up until 1780 Ma. The information is based on *in situ* SHRIMP monazite ages and ^{40}Ar - ^{39}Ar cooling ages (Berman *et al.*, *in press*; Carson *et al.*, *in press*; Sandeman, unpublished data). Foliations within the WLIC generally trend northeast-southwest with varying dip directions. Dips vary from 20 - 70° and lineations generally plunge shallowly to moderately to the north. D_1 is characterized by folds that display north and northeast axial traces while D_2 structures are generally signified by east-northeast trending fold axes. Later folding within the area is identified within the granitoids and display F_3 axial traces that generally trend north to northeast (Johnstone, 2002).

The main foliation within the CPAG reflects the regional structural trend northeast through to the Melville Peninsula. Subsequent reworking of the penetrative $S_2 \pm S_1$ fabric within the CPAG is limited to open, north-northwest- to northeast-trending

upright F_3 folds (Sandeman et al. 2001a; Sanborn-Barrie et al. 2002) and localized zones of dextral shearing (Johnstone, 2002; Sanborn-Barrie et al. 2002).

The Committee Bay belt is characterised by upper-greenschist facies metamorphism in the southwest to upper-amphibolite facies metamorphism to northeast (Schau 1982; Sanborn-Barrie et al. 2002). Metamorphism within the CPAG increases in grade in the northern section of the subdomain when approaching the Arrowsmith River shear zone (ARsz). Rocks identified near the ARsz maintain a consistent east-trending foliation with a moderate ($40-55^\circ$) dip. The intensity of foliation development ranges from moderate to high and is predominantly defined by alignment of quartz and biotite. North and north-easterly plunging lineations range from $10-20^\circ$.

The NMS contains rocks with the highest metamorphic grade in the study area. Mid- to upper-amphibolite facies grade granitoids are typically observed north of the ARsz. The ARsz is a shallow ($5-10^\circ$), south dipping shear zone that forms a structural boundary between the CPAG and the NMS. The shear zone encompasses 2 major arcuate strands of very strongly foliated and lineated to mylonitic plutonic rocks. The ARsz extends roughly 80 km across the map sheet until the easternmost strand pinches out east of the Arrowsmith River. Within this corridor, shallow ($<15^\circ$) south- to southeast-dipping mylonitic rocks are characterized by very strong rodding lineations, defined by quartz and feldspar. The eastern section is characterized by eastward plunging lineations ($<10^\circ$) and a sinistral shear sense (Sanborn-Barrie et al., 2002). Although the ARsz may delineate a metamorphic boundary with higher-grade rocks to the north, it is presently unclear whether it corresponds to a significant tectono-metamorphic break or a gradational change in metamorphic grade from south to north (Carson *et al.*, *in press*).

The NMS in general hosts penetrative northeast-trending S_2 fabrics and F_2 folds that overprint and transpose a pre-existing D_1 generation of folds and fabrics (Carson, *et al.*, *in press*). The main penetrative foliation is northeast-striking and locally interpreted as a transposition foliation (Sandeman *et al.* 2001a; Sanborn-Barrie *et al.* 2002). A moderately to strongly developed, generally northeast-plunging, L_2 mineral stretching lineation is developed on some $S_2 \pm S_1$ surfaces, and is generally co-linear with F_2 fold hinges. The S_2 fabric within the plutonic units is variably developed but generally trends northeast, typically with moderate to shallow southerly dips. An earlier bedding-parallel fabric, S_1 , can be locally identified in the hinge zones of F_2 folds, but elsewhere is indistinguishable from the $S_2 \pm S_1$ transposition fabric (Carson, *et al.*, *in press*).

Figure 2.1. Lithotectonic zones and boundaries of northeastern North America. *After* van Kranendonk *et al.* (1993), Orrell *et al.* (1999) and Johnstone (2002).

Figure 2.2. Field photo of rusty semi-pelitic rock intruded by granite dykes.

Figure 2.3. Supracrustal rocks of the Prince Albert group: a) field photo of komatiite; b) slab section of highly altered chloritic schist and; c) slab section of migmatitic paragneiss (upper portion is leucosome and lower portion is melanosome).

Figure 2.4. Intrusive rocks of the Committee Bay region: a) slab section of peraluminous, equigranular monzogranite; b) slab section of metaluminous, K-feldspar augen texture granodiorite.

Figure 2.5. Simplified map of the northern migmatite sub-domain (NMS) east of the Arrowsmith River. Map also shows location of; southern metaluminous pluton (SMP); northern metaluminous pluton (NMP); peraluminous leucogranite series (PLGS); and peraluminous classic "s-type" granite series. (PSGS)

CHAPTER 3: GEOLOGY AND DESCRIPTION OF GRANITOID ROCKS IN THE COMMITTEE BAY BELT

3.1 Introduction

This chapter will review the geology of the Committee Bay belt including a discussion of the geochronology and the structural and metamorphic history of the plutons in the region. Emphasis will be placed on the division of the plutonic rocks into coherent suites, with descriptions of field observations, mineralogy, textures, fabrics and rock distribution within the map area (Table 3.1). The division of these rocks into series is also very dependent on their geochemistry which will be discussed further in Chapter 4. This chapter will develop a geological framework and be the basis for a petrographic interpretation of the study area.

3.2 Geology of the Committee Bay area

3.2.1 Introduction

Previous mapping in the Committee Bay area has been carried out on a variety of scales since 1961. Heywood (1961; 1:500,000) and Schau (1982; 1:250,000) outlined the basic geology and recognized the overall northeast trending regional fabric.

More recent mapping in the Committee Bay area was jointly conducted by the Geological Survey of Canada (GSC) and the Canada-Nunavut Geoscience Office (C-NGO) as part of the Committee Bay Targeted Geoscience Initiative. This project has produced several maps on a variety of geological disciplines in the area (Sandeman *et al.*, 2001 a,b,c; Johnstone *et al.*, 2002 a,b; Skulski *et al.*, 2002a,b,c, 2003; MacHattie 2002; Sanborn-Barrie *et al.*, 2002; Deyell and Sherlock, 2003).

3.2.2 Geological overview of the area

The geology of the Committee Bay belt can be divided into three main components (Figure 1.3). These include: 1) the central Prince Albert group sub-domain (CPAG)- comprised of polydeformed, metamorphosed Archean supracrustal rocks from the Prince Albert group intruded by biotite±magnetite-bearing granodiorite, hornblende±biotite-bearing quartz diorite, biotite-bearing monzogranite to syenogranite and biotite-magnetite-bearing tonalite; 2) the Walker Lake intrusive complex (WLIC)- located south of the Prince Albert group and dominated by foliated Neoarchean, potassium-feldspar augen granodiorite and younger, equigranular Hudsonian monzogranites (Sandeman *et al.*, 2001a); c) the northern migmatite sub-domain (NMS)- composed of upper-amphibolite facies migmatitic paragneiss, metatexite, and diatexite (Skulski *et al.*, 2002a, 2003) intruded by Neoarchean potassium-feldspar augen granodiorite, potassium-feldspar megacrystic to coarse-grained potassium-feldspar granodiorite to monzogranite, biotite-hornblende-bearing tonalite and two distinct varieties of peraluminous granite.

3.3 Assemblages of the Committee Bay belt

3.3.1 Walker Lake intrusive complex

3.3.1.1 Geology of the Walker Lake intrusive complex

The WLIC underlies the area between Laughland Lake in the south (NTS 56 K) and the southern portion of the Walker Lake (NTS 56J north) and Ellice Hills mapsheet (NTS 56 P) (Figure 1.2). The domain can be divided into three main lithological units. These

include; 1) discrete, deformed strands of volcanic, volcanoclastic, and intercalated sedimentary rocks from the Prince Albert group which are either northeast or locally northwest striking and range from 5 to 20 km in length; 2) potassium-feldspar-augen granodiorite and; (3) generally massive biotite monzogranite (Figure 1.3).

Granitoids of the WLIC contain xenoliths composed of siliclastic rocks that were identified and interpreted as segments of the main Committee Bay supracrustal belt. These segments are composed of highly deformed amphibolite with quartzite, semi-pelitic, and psammitic siliclastic rocks and are engulfed by potassium-feldspar-augen granodiorite and equigranular monzogranite (Figure 3.1). The equigranular monzogranitic unit was identified within in the WLIC with large, up to 10 m wide, blocks of xenolithic material of granodioritic composition. The granodioritic pods are derived from a potassium-feldspar-augen granodiorite unit therefore giving field indication that the equigranular granite is much younger.

Potassium-feldspar augen granodiorite

The Neoarchean granitoids of the WLIC are dominated by potassium-feldspar augen granodiorite with massive intrusions of Hudsonian, biotite-bearing monzogranite and small volumes of PAg xenoliths comprising the remainder of the intrusive complex.

The augen granodiorite is generally well-foliated and commonly contains diffuse biotite-plagioclase-rich zones that lend the rock a schlieren texture. The rock is composed of quartz (20-30%), potassium-feldspar (35-45%), plagioclase (25-35%), and biotite (5-10%) (Figure 3.2). Potassium-feldspar is often anhedral and rounded and ranges from 0.1-1 cm in diameter. The crystals have cross-hatch twinning and contain

inclusions of small angular plagioclase and titanite. Plagioclase crystals range from 0.2-1 cm in diameter and have well-developed albite twinning. Alteration occurs around the rims of potassium-feldspar crystals and epidote locally fills millimetre-scale fractures (Figure 3.3). Biotite is euhedral to subhedral and defines the foliation within the rock. Biotite laths are also observed to rim the altered feldspars. The unit contains minor amounts of rounded magnetite crystals. The accessory minerals titanite, allanite and zircon were identified in the rock but occur in low abundance.

3.3.1.2 U-Pb geochronology

A U-Pb zircon age of ca. 2.61 Ga has been obtained on a potassium-feldspar augen granodiorite sample from an area north of the Amer fault zone (Figure 1.2) within the WLIC (Skulski, unpublished data). This age coincides with a 2.61 Ga age acquired from a biotite-bearing tonalitic intrusion found to the northeast near the shore of Walker Lake in the CPAG (Skulski, unpublished data). These geochronological results suggests a close association of Neoproterozoic plutonism within these two lithological subdomains.

The voluminous, equigranular biotite-bearing monzogranite unit, which intrudes the southernmost portions of the WLIC near the Amer fault zone and in the southern Walker Lake area, yielded a U-Pb SHRIMP zircon age of 1821 ± 5 Ma (Skulski *et al.*, 2002c). This emplacement age demonstrates that this unit comprises part of the western Churchill wide belt of Hudson granites at this time (Peterson *et al.*, 2004). These plutons have been identified at various locations with the Hearne and Rae domains and are recognized as a major plutonic event associated with Trans-Hudson orogenesis.

3.3.2 Central Prince Albert Group

3.3.2.1 Geology of the Central Prince Albert group

The CPAG is intruded by numerous plutons of biotite-bearing tonalite, hornblende-biotite-bearing-quartz diorite, biotite±magnetite-bearing granodiorite, and biotite-bearing monzogranite to syenogranite. Biotite-bearing tonalite is the oldest plutonic unit of the map area and dominates the southern portion of the sub-domain. Hornblende-biotite-bearing quartz diorite cross-cuts the biotite-bearing tonalite unit south of the Howling Wolf Lake belt. The quartz diorite unit is cut by biotite±magnetite-bearing granodiorite, which is a voluminous phase that dominates the northern section of the CPAG. The youngest plutonic phase in the CPAG is coarse-grained biotite-bearing monzogranite to syenogranite. This unit occurs as large, strongly deformed plutons exposed adjacent to the Arrowsmith River shear zone.

Xenoliths within the CPAG are identified at several locations and are vary from igneous to sedimentary in composition and mostly consist of fragments of the main supracrustal belt. The majority of the xenoliths are composed of strongly deformed amphibolite with quartzite, semi-pelitic, and psammitic siliclastic rocks and are identified within various plutonic phases within the subdomain. The biotite-bearing tonalite unit was identified within in CPAG with large, 10-100 m, blocks of supracrustal material of varying composition from amphibolite to quartz-sericite schist.

Xenoliths of igneous origin were also identified within the CPAG and were found mainly within the biotite-bearing monzogranitic to syenogranitic unit. The xenoliths are composed of granitoid material consisting of biotite-bearing tonalite to potassium-feldspar-augen granodiorite and contain well-developed foliations different in orientation

to that of the host rock. Similarly, the biotite-bearing monzogranite to syenogranite unit is seen as dykes that cross-cut these older units (Figure 3.4).

Biotite-bearing tonalite

The biotite-bearing tonalite unit is one of the most voluminous plutonic units in the Committee Bay area. The biotite-bearing tonalite is dominantly composed of plagioclase (40-50%), quartz (20-35%), potassium-feldspar (10-15%), and biotite (5-10%) (Figure 3.5). The unit varies from medium-grained to megacrystic and is mapped as large, 10-50 km long and 10-30 km wide plutons throughout the Committee Bay area. Plagioclase crystals are subhedral to euhedral and range from 0.5-1.5 cm long. Potassium-feldspar crystals are subhedral and are 0.1-0.5 cm long. Quartz is interstitial and anhedral. Biotite grains are euhedral and range from 0.1-0.3 cm long and define the foliation (Figure 3.6). The unit also contains minor, late carbonate fractures. Accessory minerals such as titanite, allanite, zircon and apatite are evident in hand sample and/or thin section.

In the southern portion of the study area (NTS 56 K) a large, 30 km in diameter, ovoid pluton consisting of biotite±hornblende-tonalite intrudes the greenstone belt (Figure 1.2). This intrusive body is known as the central tonalite and contains abundant rafts of metasedimentary and metavolcanic rocks derived from the Committee Bay belt. Away from the main body of the pluton the tonalite is observed as dykes that cross-cut the supracrustal rocks whereas the main greenstone-tonalite contact appears to be faulted (Sandeman, *et al.*, 2001a).

Hornblende-biotite-bearing quartz diorite

The hornblende-biotite-bearing quartz diorite to granodiorite unit occurs within the CPAG as 1-10 km in diameter, circular, moderately deformed plutons. The unit is medium-grained and dominantly composed of plagioclase (50-60%), quartz (5-15%), potassium-feldspar (5-15%), hornblende (5-10%), and biotite (5-7%) (Figure 3.7). Plagioclase occurs as anhedral crystals that range from 0.2-0.5 cm and contain well-developed albite twinning. Hornblende is the dominant mafic mineral and forms anhedral crystals ranging in size from 0.2-1.0 cm. Biotite grains are subhedral and range from 0.1-0.3 cm long and are often mantled by hornblende. Quartz is always interstitial and anhedral. Accessory minerals include titanite, magnetite, allanite and zircon, all in very low abundance. Titanite commonly forms small subhedral grains associated with hornblende, but also forms independent grains up to 1-2 mm in diameter.

Biotite±magnetite-bearing megacrystic granodiorite

Potassium-feldspar megacrystic granitoids in the Committee Bay area are dominated by biotite-magnetite to biotite-bearing potassium-feldspar megacrystic granodiorite (Figure 3.8). The unit comprises circular and lensoidal bodies that range from 1 to several km in length and 1-20 km in width. The granodiorites are dominantly composed of quartz (20-30%), potassium-feldspar (25-35%), plagioclase (35-45%), and biotite (5-10%). In thin section and hand specimen the major minerals display textures that are easily distinguishable from the coarse-grained to megacrystic potassium-feldspar-augen granodiorite within the study area. Potassium-feldspar crystals are tabular and euhedral and range from 1-2 cm long and contain cross-hatch twinning and perthitic exsolution lamellae. Plagioclase grains are subhedral and range from 0.2-0.5 cm in

diameter and exhibit both granophyric and myrmekitic textures. Biotite forms euhedral books up to 1 cm long whereas quartz crystals are anhedral and vary in size from 0.1-0.5 cm in diameter.

Biotite-bearing monzogranite to syenogranite

Within the NMS are voluminous, 10-30 km long bodies of biotite-bearing monzogranite to syenogranite (Figure 3.9). The unit is dominantly composed of quartz (30-45%), potassium-feldspar (20-40%), plagioclase (10-20%), and biotite (5-10%). The granitoid ranges from medium- to coarse-grained and is moderately to strongly foliated (Figure 3.10). Quartz is the dominant mineral and occurs as blebbly, anhedral crystals that range from 0.3-0.8 cm in diameter. Potassium-feldspar crystals are anhedral and range from 0.5-1.0 cm in diameter, are highly fractured and cross-hatch twinning is ubiquitous. Euhedral to anhedral biotite grains range from 0.2-0.5 cm in length and make up 5-10% of the rock. Plagioclase is anhedral and ranges from 0.1-0.3 cm in diameter with well-developed albite twinning. Magnetite is a minor phase and occurs as small rounded crystals that are 1-2 mm in diameter. The accessory minerals include titanite, allanite, apatite and zircon ranging from <1-2 mm long and <1 mm wide.

3.3.2.2 U-Pb geochronology

Only one of the main plutonic units within the CPAG has been sampled and analyzed for an emplacement age. The analysis was performed on a biotite-bearing tonalite taken from the north shore of Walker Lake and yielded an emplacement age of ca. 2.61 Ga (Skulski, unpublished data). This approximate crystallization age conflicts

with a petrologically similar biotite-bearing tonalite sampled from the NTS 56K mapsheet that yielded a U-Pb zircon crystallization age of ca. 2.72 Ga. This will be discussed in a later section of the thesis.

3.3.3 Northern Migmitite Sub-domain

3.3.3.1 Geology of the northern migmitite sub-domain

The NMS is dominated by Neoarchean, upper-amphibolite facies metasedimentary gneisses. These rocks range from psammitic to pelite in composition. This sequence is believed to represent an uppermost, clastic rock-dominated component of Prince Albert group stratigraphy (Skulski et al. 2002a, 2003). Granitoids in the subdomain include biotite-magnetite-bearing megacrystic granodiorite and biotite-bearing tonalite, similar to those previously described, in the CPAG. Other granitoid units in the NMS consist of biotite-hornblende-bearing tonalite and a peraluminous series that includes biotite-muscovite-garnet±sillimanite-bearing granodiorite, and biotite-muscovite monzogranite and syenogranite. These units are more commonly identified within the NMS than elsewhere in the Committee Bay belt.

Xenoliths within the NMS are identified at several locations and vary from igneous to sedimentary in composition and mostly consist of fragments of the main supracrustal belt. The majority of the xenoliths are highly deformed refractory iron-formation and psammitic siliciclastic rocks and range in size from centimetre-scale lenses to metre-scale angular blocks. An example of this is seen near the ARsz where biotite-muscovite-garnet-bearing monzogranite intrudes supracrustal rocks (Figure 3.11).

Hornblende-biotite-bearing tonalite

The hornblende-biotite-bearing tonalite unit occurs as large kilometre-scale plutons and small (1-3 km long) lensoidal bodies throughout the Committee Bay belt region. Near the ARsz this unit is interlayered with amphibolitic rocks of the PAg (Figure 3.12). The tonalite is dominantly composed of quartz (20-35%), plagioclase (40-50%), potassium-feldspar (10-15%), and biotite and hornblende (5-10%). The rock is fine- to medium-grained with anhedral to subhedral plagioclase crystals that range from <1-5 mm in diameter (Figure 3.13). Hornblende is anhedral and 0.2-0.5 cm in diameter with rounded quartz inclusions. Potassium feldspar is anhedral to subhedral and ranges from 1-3 mm in diameter. Quartz is interstitial and anhedral. The rock is biotite-rich (5-10%) with euhedral crystals forming 0.1-0.3 cm long laths. Magnetite grains are <1 mm in diameter and are sub-rounded. In thin-section, accessory minerals include epidote, titanite, allanite, apatite and zircon. Epidote forms both interstitial euhedral and subhedral grains. Titanite commonly forms subhedral grains that are 0.1-0.3 cm in diameter and is usually spatially associated with hornblende.

All hornblende-biotite-bearing tonalities have a moderately to strongly developed foliation defined by the planar alignment of biotite and hornblende. This hornblende-biotite-developed foliation is best developed in proximity to the Walker Lake shear zone where late D₂ deformation resulted in shortening and dextral transpressive shearing of these rocks (Johnstone, 2002).

3.3.3.2 U-Pb geochronology

U-Pb SHRIMP analyses have been performed on zircon and monazite from two types of granitoids from the NMS. An emplacement age of 2.58 Ga was determined for a biotite-magnetite-bearing granodiorite intrusion (Carson, *et al.*, *in press.*). This unit has a crystallization age similar to a suite of granodiorites exposed northwest of the Committee Bay area near Chantry Inlet (Frish and Parrish, 1992). The second granitoid unit to be analysed from the NMS was a biotite-muscovite-garnet-bearing granite which displayed several discordant ages. Analysis of this particular sample yielded ages ranging from 2280-2677 Ma. In the Chantry Inlet area, petrologically comparable plutonic rocks were also analyzed by TIMS U-Pb analysis on zircon and yielded discordant ages ranging from 2591-2597 Ma but suggesting that the rocks crystallized ca. 2590-2595.

3.4 Field Relationships and Petrography of the Peraluminous Granite Series

3.4.1 Introduction

Several granitoid phases in the NMS are exposed within a small area east of the Arrowsmith River (Figure 2.5). These include two petrologically distinct varieties of peraluminous and three types of metaluminous granitoids. The metaluminous granitoids comprise two large plutons that cross-cut the country metasedimentary rocks. These constitute the northern metaluminous pluton (NMP) and southern metaluminous pluton (SMP), respectively. Peraluminous granitoids within the area are less voluminous and are subdivided into two distinct associations: 1) two-mica leucogranite and; 2) “classic” S-type biotite-muscovite-garnet±sillimanite-bearing monzogranite to granodiorite. Much debate has focused on the origin of peraluminous rocks and in light of this, Patino-Douce (1999) proposed a clearer subdivision of the peraluminous clan. Using the results of

melting experiments and the major element compositions of several representative types of natural peraluminous granitic rocks, that author distinguished peraluminous, two-mica leucogranites (“PLGS”) as markedly different from peraluminous S-type granites (“PSGS”). Patino-Douce (1999) emphasized that among common peraluminous granite types the PLGS are likely to represent pure anatectic melts.

3.4.2 Peraluminous leucogranite series

Rocks of the PLGS suite are most prominent in the NMS and occur as small lensoidal bodies that are 1-3 km long and approximately 500 m wide and as dykes that cross-cut the metasedimentary rocks of the domain. These are equigranular, medium- to coarse-grained biotite-muscovite-bearing monzogranite to syenogranite (Figure 3.14). The PLGS are dominantly composed of quartz (30-40%), microcline (25-40%), plagioclase (25-35%), and biotite (<5%). Microcline grains exhibit cross-hatch twinning and are anhedral to sub-hedral ranging from 0.5-1 cm in diameter. Biotite is euhedral and ranges from 0.2-0.5 cm in length. Muscovite makes up <3% of the rock and crystals are euhedral ranging up to 0.3 cm long. Accessory minerals include titanite, allanite and zircon.

These equigranular granitoids are locally found near the boundary between the megacrystic biotite-magnetite to biotite-bearing megacrystic potassium-feldspar granodiorites and the metasedimentary units in the NMS, in particular, near the SMP (Figure 2.5). Unfortunately polyphase deformation and extensive quaternary cover has made original contact relationships difficult to determine, but nevertheless, the PLGS were locally observed to cross-cut the megacrystic granodiorites. The observed

relationships do not preclude or necessitate a genetic relationship between the PLGS and the megacrystic granodiorites.

3.4.3 Peraluminous S-type granite series

Rocks of the PSGS suite occur exclusively in the NMS and occur as lensoidal intrusive bodies that range in length from 1-10 km, as well as dykes that cross-cut the diatexite and metatexite of this domain. These granitoids are medium- to coarse-grained biotite-garnet±muscovite±sillimanite-bearing granodiorite to monzogranite (Figure 3.15). The rock is dominantly composed of quartz (20-35%), microcline (20-35%), plagioclase (25-35%), and biotite and muscovite (5-10%). The rock is coarse-grained to megacrystic with microcline ranging from 0.5-2.0 cm in length. Microcline grains are subhedral to euhedral and exhibit cross-hatch twinning and granophyric textures (Figure 3.15b). Biotite grains are euhedral and range from 0.2-0.5 cm in length and make up 5-10% of the rock. Muscovite grains are euhedral and range from 0.2-0.5 cm long and typically wrap around garnet. Garnet grains are anhedral and 0.2-1.0 cm in diameter and commonly contain inclusions of alumina-rich minerals such as muscovite and sillimanite. Rare accessory minerals include titanite, allanite and zircon.

The PSGS occurs along the margins of the SMP. The SMP is a zoned pluton which grades from the core outward from small, 100-500 m bodies of orthopyroxene-bearing granodiorite to a biotite±magnetite-bearing granodiorite (Figure 2.5). Owing to poor exposure, clear contact relations between the peraluminous granites and the SMP were not identified. The proximity of the two units, together with similarities in feldspar textures (presence of granophyres) suggests a possible genetic link. This lack of

unambiguous field evidence indicates that further evaluation of a possible genetic link between these two units may only be discerned through geochemical comparison. This will be discussed further in chapter 4.

3.5 Summary

Available U-Pb geochronology, both from the Committee Bay belt and nearby Chantry Inlet area, indicate that plutonic activity in the region occurred during the interval 2.72-2.58 Ga. Geochronological data indicate that granitoid rocks are only rarely cogenetic with the Neoarchean greenstone belt rocks in the region and the majority of granitoids in the region crystallized between the interval 2.61 to 2.58 Ga, or at ca. 1.825 Ga (Skulski *et al.*, 2002; Skulski, *unpublished data*; Frisch and Parrish, 1992).

The oldest, and less voluminous, plutonic phase in the Committee Bay region is a homogeneous tonalitic pluton that intruded the Committee Bay crustal belt ca. 2.72 Ga. This intrusion is recognized as the first phase of major plutonism that cross-cuts the supracrustal belt.

Younger granitoid phases within the map area consist of biotite-bearing monzogranite and syenogranite and biotite-bearing granodiorites. These units are considered to have been emplaced during the interval 2.61-2.58 Ga. Within the NMS, SHRIMP analyses of the biotite±magnetite-bearing potassium-feldspar megacrystic granodioritic unit yielded a crystallization age of 2580 ± 8 Ma (C. Carson, *unpublished data*).

The NMS also hosts two distinct peraluminous granitic phases that are considered products of anatectic and peritectic dehydration melting that occurred during

migmatization of the metasedimentary rocks. One of these peraluminous phases (PSGS) will be further evaluated geochemically in an effort to determine any possible genetic relationship between this adjacent biotite±magnetite megacrystic granodiorite unit.

Figure 3.1. Monzogranitic unit intruding semi-pelitic rocks of the Committee Bay belt.

Figure 3.2. Photos of K-feldspar augen granodiorite unit: a) field photo of pink K-feldspar augen granodiorite; b) slab section of pink K-feldspar augen granodiorite and; c) field photo of white K-feldspar augen granodiorite.

Figure 3.3. Photomicrographs of K-feldspar augen granodiorite (xpl); a) textural appearance of unit; b) blebby quartz and biotite defining the foliation of the rock; c) cross-hatch twinning within the feldspars and; d) epidote alteration around a feldspar megacryst.

Figure 3.4. Field photos of bio-bearing monzogranite: a) bio-bearing monzogranite dyke intruding bio±mag-bearing granodiorite unit and; b) bio-rich monzogranite intruding bio-bearing tonalitic gneiss.

Figure 3.5. Photos of bio-bearing tonalite: a) field photo of bio-bearing tonalite; b) highly deformed bio-rich tonalitic gneiss and; c) slab section of bio-bearing tonalite.

Figure 3.6. Photomicrographs of bio-bearing tonalite: a) bio-rich portion of sample (xpl); b) bio defining the foliation (ppl) and; c) textural appearance and mineralogy (xpl).

Figure 3.7. Photos of hbl-bio-bearing quartz diorite: a) slab section of quartz diorite; b) photomicrograph (scale = 400 μm) showing quartz diorite mineralogy (ppl) and; c) photomicrograph (scale = 400 μm) showing quartz diorite mineralogy (xpl).

Figure 3.8. Photos of bio±mag-bearing granodiorite: a) slab section of unit; b) photomicrograph (scale = 400µm) showing bio±mag-bearing granodiorite texture (xpl); c) mineral inclusions within cleavage planes of feldspar (xpl)(scale = 300µm) and; d) granophyric texture (scale = 200µm).

Figure 3.9. Field photo of bio-bearing syenogranite (a) and bio-bearing monzogranite (b).

Figure 3.10. Photomicrographs of monzogranite: a) texture and mineralogy of unit (xpl) (scale = 400µm) and; b) myrmekitic texture (xpl).

Figure 3.11. Field photos of bio-musc-grt-bearing monzogranite: a) monzogranitic dykes cutting metasediments and; b) boudinaged bio-musc-grt-bearing monzogranite dyke cutting refractory iron-formation within the NMS.

Figure 3.12. Highly strained bio-bearing tonalite with deformed amphibolite found near the Arrowsmith River shear zone (hammer for scale).

Figure 3.13. Photos of bio-hbl-bearing tonalite: a) field appearance of unit; b) slab section of unit; c) textural appearance (ppl) (scale = 400μm) and; d) textural appearance (xpl) (scale = 400μm).

Figure 3.14. Photos of PLGS: a) field photo of PLGS intruding metasediments; b) slab section of unit and; c) photomicrograph showing texture and mineralogy (xpl) (scale = 300 μ m).

Figure 3.15. Photos of PSGS: a) slab section of PSGS; b) photomicrograph showing textures in feldspars (xpl) and; photomicrograph showing garnet with sillimanite inclusions.

Table 3.1. Summary of the field and petrological characteristics of the major granitoid divisions in the Committee Bay region.

GRANITOIDS IN THE WALKER LAKE INTRUSIVE COMPLEX

potassium-feldspar augen granodiorite (KAGS)

- WLIC predominantly comprised of KAGS
- xenoliths composed of siliclastic rocks such as quartzite, semi-pelite, and psammite and highly deformed amphibolite
- well-foliated and commonly contains diffuse biotite-plagioclase-rich zones that lend the rock a schlieren texture
- potassium-feldspar has cross-hatch twinning and contain inclusions of small angular plagioclase and titanite
- plagioclase crystals range from 0.2-1 cm in diameter and have well-developed albite twinning
- saussuritization commonly occurs within the rims of the potassium-feldspar crystals and epidote locally fills millimetre-scale fractures
- unit contains minor amounts of rounded magnetite crystals
- U-Pb zircon age of ca. 2.61 Ga

GRANITOIDS IN THE CENTRAL PRINCE ALBERT GROUP

hornblende-biotite quartz diorite (HBDS)

- forms circular, moderately deformed plutons that a few kilometres in diameter
- medium-grained and dominantly composed of plagioclase
- hornblende is the dominant mafic mineral
- quartz is always interstitial
- accessory minerals include titanite, magnetite, allanite and zircon
- titanite commonly forms small subhedral grains associated with hornblende

biotite-bearing tonalite (BTS)

- most voluminous plutonic units in the Committee Bay area
- large, 10-50 km long and 10-30 km wide bodies
- the unit also contains minor, late carbonate fractures
- accessory minerals such as titanite, allanite, zircon and apatite
- U-Pb emplacement ages range between 2.72-2.61 Ga.

biotite-bearing potassium-feldspar megacrystic granodiorite (BMGS)

- the unit comprises circular and lensoidal bodies that range from 1 to several km in length and 1-20 km in width
- easily distinguishable from the coarse-grained to megacrystic potassium-feldspar augen granodiorite (KAGS)
- the majority of the xenoliths are composed of strongly deformed amphibolite with quartzite, semi-pelitic, and psammitic siliclastic rocks
- potassium-feldspar crystals are tabular and euhedral and range from 1-2 cm long and contain cross-hatch twinning and perthitic exsolution lamellae
- feldspars with granophyric and myrmekitic textures

- U-Pb emplacement age of 2.58 Ga was determined

biotite-bearing monzogranite to syenogranite (BMSS)

- unit ranges from medium- to coarse-grained and is moderately to strongly foliated
- potassium-feldspar crystals are anhedral, highly fractured and has cross-hatch twinning
- plagioclase is anhedral and ranges from 0.1-0.3 cm in diameter with well-developed albite twinning
- magnetite is a minor phase and occurs as small rounded crystals that are 1-2 mm in diameter
- accessory minerals include titanite, allanite, apatite and zircon

GRANITOIDS IN THE NORTHERN MIGMITITE SUB-DOMAIN

hornblende-biotite tonalite (HBTS)

- occur as large kilometre-scale plutons and small (1-3 km long) lensoidal bodies
- moderately to strongly developed foliation
- unit can be seen interlayered with amphibolitic rocks
- fine- to medium-grained
- hornblende is anhedral and 0.2-0.5 cm in diameter with rounded quartz inclusions
- magnetite grains can be found as well as accessory minerals include epidote, titanite, allanite, apatite and zircon

peraluminous, two-mica leucogranite (PLGS)

- equigranular, medium- to coarse-grained biotite-muscovite-bearing monzogranite to syenogranite
- occurs as small lensoidal bodies that are 1-3 km long and approximately 500 m wide and as dykes that cross-cut metasedimentary rocks
- microcline grains exhibit cross-hatch twinning
- biotite is euhedral and muscovite makes up <3% of the rock and crystals
- accessory minerals include titanite, allanite and zircon
- cross-cut the megacrystic granodiorites

classic “s-type” granites (PSGS)

- medium- to coarse-grained biotite-garnet±muscovite±sillimanite-bearing granodiorite to monzogranite
- occur as lensoidal intrusive bodies that range in length from 1-10 km and dykes that cross-cut the metasediments
- dominantly composed of quartz, microcline, and, plagioclase
- coarse-grained to megacrystic
- cross-hatch twinning and granophyric textures
- rare accessory minerals include titanite, allanite and zircon
- possible genetic link between “s-type” granite and granodiorite in the area due to similar textures

CHAPTER 4: LITHOGEOCHEMISTRY AND ND ISOTOPIC SIGNATURE OF THE COMMITTEE BAY PLUTONS

4.1 Introduction

The main granitoid divisions, as described in chapter 3, were sampled and analyses were performed to determine geochemical and isotopic characteristics. The resultant data will allow for a more detailed and accurate approach in developing a petrogenetic model for the Committee Bay granitoids.

From the granitoid sub-divisions a total of 83 samples were selected for major and selected trace elements by X-ray fluorescence spectrophotometry, 65 samples for trace and rare earth element concentrations by inductively-coupled plasma mass spectrometry, and 15 samples for their Sm and Nd isotopic compositions. Whole rock analyses for major, trace and rare earth elements are listed in Tables 4.1a and b. Isotopic data are listed in table 4.2.

4.2 Geochemistry of the Neoarchean granitoids

4.2.1 Major elements

Figure 4.1 is a quartz-alkali-feldspar-plagioclase feldspar (QAP) mesonorm diagram with field categories from Streckheisen (1976). The diagram shows that the samples are clustered within the granodiorite, tonalite, granite and quartz diorite fields.

Figures 4.2 and 4.3 are Harker diagrams that compare weight percentage of SiO_2 and major element values of Al_2O_3 , TiO_2 , K_2O , CaO , Na_2O , MgO , P_2O_5 , and Fe_2O_3 . With increasing SiO_2 the major elements TiO_2 , Al_2O_3 , CaO , MgO , P_2O_5 , and Fe_2O_3

decrease, K_2O steadily increases and Na_2O displays a flat and scattered trend. Further elemental analyses of individual granitoid suites will be discussed below.

The widest range of silica content of all the Neoproterozoic granitoids occurs within the BMGS. This suite has silica contents ranging from 60-75 wt. % and shows smooth changes in the major elements with increasing SiO_2 . The SiO_2 versus Al_2O_3 , TiO_2 , CaO , MgO , P_2O_5 , and Fe_2O_3 plots display smooth curvilinear trends while the Na_2O and K_2O plots show significant scatter.

The KAGS has a silica content range from 63-75 wt. %. This suite, like the BMGS is granodioritic in composition that on average is slightly more felsic than the BMGS and lacks the presence of magnetite. Both granodiorite types show similar major element trends, and similar concentrations of K_2O and MgO . However, the KAGS have lower weight percent values of major elements such as Al_2O_3 , CaO , and Na_2O and higher values of TiO_2 , P_2O_5 , and Fe_2O_3 , when compared to the BMGS.

The BTS has silica contents ranging from 63-70 wt. %. Major element plots for Al_2O_3 , TiO_2 , CaO , MgO , P_2O_5 , and Fe_2O_3 show decreasing concentrations with increasing silica. Na_2O and K_2O plots display scattered distribution.

The BMSS displays silica content between 70-78 wt. %. This suite is more felsic than other granitoids and concentrations of Al_2O_3 , TiO_2 , CaO , MgO , P_2O_5 , and Fe_2O_3 display plots with smooth curvilinear trends that show decreasing concentration with increasing silica. The Na_2O plot has significant scatter while the K_2O plot shows the highest values accredited to the BMSS. The high concentrations of K_2O is the result of the high volume of potassium-feldspar in this suite.

The HBTS has a silica content range from 56-69 wt. %. This suite, like the BTS, is tonalitic in character and is more mafic than the BTS due to the presence of hornblende. The HBTS displays similar major element trends and overlaps in composition with the BTS and suggests that the two series' are cogenetic.

The HBDS has the fewest number of analyzed samples which is the result of it having the lowest volume of all the main granitoid divisions for the Committee Bay belt. This suite has the lowest silica content, 50-55 wt. %, and is the most mafic suite in this study. Where the Harker diagrams have a positive sloping trend (K_2O and Na_2O), with respect to the SiO_2 differentiation, the HBDS has lower major element values. Where the Harker diagrams have a negative slope the HBDS has higher values (Al_2O_3 , TiO_2 , CaO , MgO , P_2O_5 , and Fe_2O_3), when compared to all other granitoids.

4.2.1.1 Magma suites and alumina index

An important step in describing igneous rocks is determining which magma series/suites they belong to. In large part, the concept of magma series (spatial, non-genetic association) or magma suites (common lineage or source material) is based on geochemical variations in volcanic rocks, where the assumption that the bulk composition represents the liquid composition is more easily ascertained (Carmichael, *et al.*, 1974). It is also important to define the plutonic rocks in terms of their alkaline, tholeiitic or calc-alkalic nature in order to classify the nature of plutonism.

Figure 4.4 displays total alkalis ($Na_2O + K_2O$) versus SiO_2 (Irvine and Barager, 1971). All granitoids here are sub-alkaline (either tholeiitic or calc-alkaline) with HBDS being transitional to alkaline. Figure 4.5 further defines their sub-alkaline character with

the aid of the AFM (alkalis, FeO* and MgO) ternary diagram (Irvine and Barager, 1971). All rocks here are calc-alkaline in nature with the exception of one quartz diorite (HBDS) that plots in the tholeiitic field.

Figure 4.6 illustrates K_2O versus SiO_2 with field boundaries modified from Peccerillo and Taylor (1976). The plot displays the KAGS defining a high calc-alkaline trend with one sample plotting in the shoshonite field. The BMGS mostly plot in the high calc-alkaline field with four samples plotting as weakly shoshonitic. The HBTS define a calc-alkaline to high calc-alkaline trend as does the BTS. The BMSS define a high calc-alkaline to shoshonitic trend while the HBDS has one sample in the calc-alkaline field and all others plot in the high calc-alkaline field.

The molecular $Al_2O_3/(CaO + Na_2O + K_2O)$ versus $Al_2O_3/(Na_2O + K_2O)$ plot (Maniar and Piccoli, 1989) is used to differentiate between peraluminous and metaluminous igneous rocks (Figure 4.7). All rocks here are metaluminous to weakly peraluminous, with a cluster of KAGS samples and one HBTS sample plotting on the peraluminous field boundary line ($A/CNK = 1.1$). KAGS samples mainly plot in the weakly peraluminous field ($A/CNK = 1.0-1.1$). The BMSS rocks are weakly metaluminous to weakly peraluminous as are the majority of BTS and BMGS samples. HBTS and HBDS rocks plot mainly in the metaluminous peralkaline field with the exception of one anomalous value.

4.2.2 Trace Elements

When plotted on Harker diagrams the trace element data for the Committee Bay granitoids show significant scatter. Given the size of the Committee Bay area, the

lithological composition variation, the varieties in metamorphic grade and the various accessory minerals associated with the units, the data scatter is expected. Nonetheless, general trends associated with the granitoid divisions can be identified. For the trace element Harker diagrams SiO_2 has been plotted against high field strength elements (HFSE) and low field strength elements (LFSE) in Figures 4.8 and 4.9.

4.2.2.1 Trace elements of the metaluminous granitoids

The trace element chemistry for the metaluminous granitoids show generally increasing concentrations of Pb, Th and Rb with increasing silica content (Figures 4.8 and 4.9) whereas Sr decreases. The elements Zr, Nb and Ba show increasing concentrations to approximately 65% silica then begin to decrease.

The KAGS has high amounts of Rb (62-172 ppm), Pb (16-40 ppm), and Ba (700-1200 ppm) moderate amounts of Y (5-22 ppm), Th (3-12 ppm) and Nb (7-15 ppm). Concentrations of Zr (123-373 ppm) and Sr (183-588 ppm) range from moderate to high. Between the 62-70% silica range the elements Nb, Rb, Th, Pb begin to decrease in concentration with higher fractionation and within the 65-70% silica range concentrations of Pb, Th, and Rb are high for the KAGS when compared to other Committee Bay granitoids. The BMGS has high amounts of Ba, Y, Nb, and Zr between 62-70% wt. % silica that decrease with higher fractionation. Concentrations range from Ba (900-1600 ppm), Y (15-30 ppm), Nb (15-29 ppm), and Zr (300-420 ppm). The BMGS is a suite of granodiorites and has similar trace element compositions as the KAGS. The monzogranites and syenogranites of the BMSS also have similar trace element values and largely plot as extrapolations to the KAGS and BMGS trends. These samples have

similarly high values of Ba (900-1100 ppm), Nb (17-30 ppm), Rb (176-226), and Pb (25-37 ppm) between 62-70% silica.

The HBDS shows the lowest values on Harker diagrams with a positive slope and the highest values on those with a negative slope, with respect to increasing fractionation. Concentrations of Ba (200-400 ppm), Rb (23-78 ppm), Pb (6-12 ppm) and Th (1-6) are the lowest of all granitoid units. Concentrations of Y (15-25 ppm), Zr (85-110 ppm) and Nb (5-11 ppm) reflect those of the BTS. The BTS trends display high concentrations of Pb (20-30 ppm) and Sr (400-630 ppm) and moderate concentrations of Zr (100-180 ppm), Nb (4-8 ppm), and Y (11-20 ppm). Significant scatter occurs with Rb (50-150 ppm).

The HBTS contains high concentrations of Sr (400-691 ppm) and moderate concentrations of Zr (100-150 ppm) and Nb (5-12 ppm). Low concentrations of Rb (40-100 ppm) and Y (4-10 ppm) occur in this suite. Significant scatter occurs with Ba (150-1000 ppm) and the most notable increase occurs with Th (5-20 ppm) with increasing silica. When grouped the plagioclase-rich HBTS, BTS, and HBDS extrapolate along different trends compared to the potassium-feldspar-rich BMGS, KAGS and BMSS. This will be discussed further in the chapter summary.

4.2.3 Rare earth element diagrams

All REE data have been normalized to primitive mantle values obtained from Sun and McDonough (1989) with results displayed in Figure 4.10. Comparing similarly fractionated rocks is very important, therefore, the metaluminous granitoids are subdivided into four categories based on weight percent silica (61-63 wt. %, 64-66 wt. %, 67-72 wt. % and <60 wt. %).

REE patterns for samples of metaluminous granitoids with 61-63 wt. % silica have similar trends and abundances. All suites in this range are moderately to highly fractionated with $\{(La/Yb)_N = 5-15\}$ and contain low to moderate REE contents. The KAGS has $(Ce)_N = 50$; BMGS has $\{(Ce)_N = 55-70\}$ and; HBTS has $(Ce)_N = 25-30$. The KAGS has $(Yb)_N = 3$, BMGS has $(Yb)_N = 3-6$ and HBTS has $(Yb)_N = 1-3$ and negative Eu anomalies $(Eu/Eu^*)_N = 0.6-0.9$. The bio-mag-granodiorite suite is more fractionated, has higher REE values and has similar negative Eu anomalies as the KAGS and HBTS. The least negative Eu anomaly is accredited to the least evolved sample which is part of the HBTS.

REE patterns for the metaluminous granitoids with 64-66 wt. % silica have different trends and abundances. The granitoids that fall in this range are highly fractionated with $(Ce)_N = 30-69$ and $(Yb)_N = <1-4$, have a slightly concave upwards MREE and HREE trend, and have positive to very slightly negative Eu anomalies $(Eu/Eu^*)_N = 0.9-1.5$. The degree of LREE fractionation is highly variable within the KAGS $(La/Sm)_N = 2-4$ when compared with the HBTS $(La/Sm)_N = 3-3.3$, the BTS $(La/Sm)_N = 2.7-3$, and the BMGS $(La/Sm)_N = 3-3.5$. Within this wt. % silica range both suites of granodiorites (KAGS and BMGS) contain the smallest Eu anomalies.

REE patterns for felsic samples that range from 67-72 wt. % silica have different patterns and abundances. The BMGS, KAGS and BMSS have the highest REE contents: BMSS with $(Ce)_N = 50-80$ and $(Yb)_N = 2-4.5$; KAGS with $(Ce)_N = 40-85$ and $(Yb)_N = 1.2-3.7$ and; BMGS with $(Ce)_N = 29-60$ and $(Yb)_N = 1-4.2$. All granitoids in this silica range are highly fractionated $(La/Yb)_N = 15-40$. Eu anomalies are generally more

negative within the potassium-feldspar-dominant rocks than in the plagioclase-dominant units and overall the range values are $(\text{Eu}/\text{Eu}^*)_N = 0.5-2$.

REE patterns for granitoids containing <60 wt. % silica are plotted in Figure 4.10d. The HBDS are moderately fractionated with $(\text{La}/\text{Yb})_N = 5-15$ and Eu anomalies are slightly negative $(\text{Eu}/\text{Eu}^*)_N = 0.8-0.95$. Both tonalite suites (BTS and HBTS) are slightly fractionated with $(\text{La}/\text{Yb})_N = 5-10$ and Eu anomalies are slightly negative $(\text{Eu}/\text{Eu}^*)_N = 0.8-0.9$ with the exception of one sample that has a value of $(\text{Eu}/\text{Eu}^*)_N = 1.8$. The quartz diorites of the HBDS are slightly fractionated with $(\text{La}/\text{Yb})_N = 5-10$ and Eu anomalies are very slightly negative $(\text{Eu}/\text{Eu}^*)_N = 0.9-0.94$. The HBDS has a moderate MREE and HREE content $(\text{Ce})_N = 25-55$ and $(\text{Yb})_N = 3-4$ and the two tonalite suites (BTS and HBTS) have moderate to high MREE and HREE concentrations $(\text{Ce})_N = 40-60$ and $(\text{Yb})_N = 2.5-4.1$.

4.2.4 Extended element diagrams

Figures 4.11a, b, c and d illustrate extended element diagrams with primitive mantle normalized values (Sun and McDonough, 1989) of selected REE, LFSE (Rb, Ba, Sr and K) and HFSE (Th, Nb, Zr, P, Ti and Y). The element order is based on increasing incompatibility towards the left (Whalen *et al.*, 1999). The silica groupings used for the REE diagrams are also applied to the extended element diagrams.

All extended element diagrams for the metaluminous granitoids (Figure 4.11) with silica contents >60 wt. % show elevated Rb, K and LREE and low Nb, Zr, P, Ti and HREE contents. Pronounced positive Ba anomalies and negative Nb, Sr, P, and Ti anomalies are observed.

Extended element diagrams for the 61-63 wt. % silica range are plotted in figure 4.11a. Two samples of the HBTS show slightly negative Ba, Zr, and P anomalies and large negative Nb and Ti anomalies. One sample of the KAGS show slightly negative P anomaly and large negative Nb and Ti anomalies. Three samples of the BMGS show slightly positive Ba (with the exception of one) and large negative Nb, Sr, P and Ti anomalies. The BMGS and KAGS samples in this silica range have higher concentrations of all elements plotted than does the HBTS.

Figure 4.11b displays extended element diagrams for samples that fall in the 64-66 wt. % silica range, all of which are very similar excluding a sample from the BMGS. Two samples of the HBTS show slightly negative Ba, Sr, and P anomalies and strong negative Nb and Ti anomalies. The HBTS have the lowest concentration of selected elements of all suites that plot in the 64-66 wt. % silica category. Two samples of the KAGS have very similar extended element compositions as the HBTS in that they show slightly negative Ba, Sr, and P anomalies and strong negative Nb and Ti anomalies, but have overall higher concentrations of these elements. One sample of the BTS shows slightly negative Ba, Sr, Zr and P anomalies and strong negative Nb and Ti anomalies. The one sample from the BMGS shows slightly positive Ba and and less negative Th, Nb, Sr and Ti anomalies when compared to all other samples in the diagram.

Extended element diagrams for the 67-72 wt. % silica range are plotted in figure 4.11c and illustrates that the felsic samples have very similar patterns but with a strong variation in HREE concentrations. All samples, with the exception of one BTS sample, have slightly positive Th and strongly negative Nb, Sr, P and Ti anomalies. The BMSS has higher concentrations of the selected elements (with the exception of La and Ce

which is higher in the BMGS) and is also enriched in the HREE's when compared to other rocks that fall into this silica range.

Extended element diagrams for the <60 wt. % silica range are plotted in Figure 11d. Samples that fall in this range have the lowest concentrations of the selected elements and the largest variety in plot patterns among all metaluminous granitoid samples. The HBDS display strong negative Nb, Sr and Ti anomalies and weakly negative Sr anomalies. One sample of quartz diorite has low concentrations of LREE and displays negative Th, La, Nb and Ce anomalies. The BTS is represented in this silica range and shows slightly positive Ba, a slightly negative Sr anomaly, and strong negative Nb and Zr anomalies. The HBTS, like the BTS, also shows slightly a positive Ba anomaly, a slightly negative Sr anomaly, and strong negative Nb and Zr anomalies. The HBTS sample that falls in the <60 wt. % silica range is the only metaluminous granitoid that doesn't have a negative Zr anomaly.

4.2.5 Sm and Nd isotopes

Various phases of granitoid rocks of the Committee Bay area have different crystallization ages. For example, biotite-bearing tonalite, hornblende-biotite-bearing tonalite, and potassium-feldspar augen granodiorite crystallization ages are ca. 2.61 Ga (with one biotite-bearing tonalite sample calculated at ca. 2.72 Ga) and ages of biotite±magnetite-bearing granodiorites and biotite-bearing monzogranites ca. 2.58 Ga (with one biotite±magnetite-bearing granodiorite sample at ca. 2.6 Ga). These various ages, along with present day CHUR values of $^{143}\text{Nd}/^{144}\text{Nd} = 0.512638$ and $^{147}\text{Sm}/^{144}\text{Nd} = 0.1967$, were used to calculate initial $^{143}\text{Nd}/^{144}\text{Nd}$ and ϵNd (Table 4.2). ϵNd versus silica,

$(\text{La/Yb})_N$, and $(\text{La/Sm})_N$ are illustrated in figure 4.12. The Committee Bay granitoids have $\epsilon\text{Nd}(t)$ values that range between -2.00 to +3.71 and show no apparent relationship with silica (Figure 4.12a) or REE fractionation (Figure 4.12b, c).

The highest $\epsilon\text{Nd}(t)$ values occur within the plagioclase-rich units (BTS, HBTS, and HBDS). The tonalites and quartz diorites that make up these rock suites have $\epsilon\text{Nd}(t)$ values that range from +0.79 to +3.51. Five samples were selected from various locations within the NTS 56K and NTS 56J/O map sheets within a range of approximately 200 km. Two samples of bio-bearing tonalite have $\epsilon\text{Nd}(t)$ values of +2.57 and +3.51 with one anomalously low sample at +0.79. One sample of hornblende-biotite-bearing tonalite has a value of +1.75 and a quartz diorite sample has a value of +2.42.

The lowest $\epsilon\text{Nd}(t)$ values occur within the potassium-feldspar-rich units (BMGS, KAGS, and BMSS). The granodiorites and monzogranites that comprise these rock suites have $\epsilon\text{Nd}(t)$ values ranging from -2.00 to -0.04. Five samples were selected from locations within the NTS 56K and NTS 56J/O map sheets and span an area of approximately 250 km. A sample of potassium-feldspar augen granodiorite shows an $\epsilon\text{Nd}(t)$ value of -0.04, three samples of biotite-bearing monzogranite to syenogranite show values ranging from -0.75 to +0.16 and one sample of biotite±magetite-bearing granodiorite has a lower value of -2.00.

4.3 Geochemistry of the peraluminous granite series

4.3.1 Introduction

The previous section discussed the geochemical character of the metaluminous granitoids that comprise the majority of plutonic rocks in the Committee Bay area. This section describes the geochemical character of the peraluminous granitoids associated with the Committee Bay area and compares/contrasts these with the metaluminous units.

4.3.2 Major elements

Figure 4.13 is a quartz-alkali-feldspar-plagioclase feldspar (QAP) mesonorm diagram with field categories from Streckheisen (1976). This diagram shows all samples plotting in the granodiorite and granite field.

Figure 4.14 and 4.15 are Harker diagrams that compare weight percentage of SiO_2 and major element values of Al_2O_3 , TiO_2 , K_2O , CaO , Na_2O , MgO , P_2O_5 , and Fe_2O_3 . The range of silica content varies from 67-74% for the PLGS and from 71-77% for the PSGS.

The Harker diagram for the PLGS illustrates a decreasing trend for TiO_2 , CaO , Na_2O , MgO , and Fe_2O_3 with respect to increasing silica content. Weight percent values for K_2O increase with higher silica while P_2O_5 and Al_2O_3 trends are flat and indicate very little concentration change. The PSGS displays a decreasing trend for Al_2O_3 , TiO_2 , P_2O_5 and MgO with respect to increasing silica. CaO concentrations display a flat trend and K_2O , Na_2O and Fe_2O_3 values display a scattered pattern.

4.3.2.1 Magma suites and alumina indices

As previously mentioned, it is important to define the plutonic rocks in terms of their alkaline, tholeiitic or calc-alkalic nature. This is displayed here by means of various major element plots.

Figure 4.16 displays total alkalis ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) versus SiO_2 and shows that all peraluminous series rocks here are sub-alkaline (either tholeiitic or calc-alkaline). Figure 4.17 further defines their sub-alkaline character and shows that the series is calc-alkaline in nature. Figure 4.18 illustrates K_2O versus SiO_2 . The plot displays both the PLGS and PSGS as being high-K calc-alkaline to shoshonitic with the PSGS having, on average, a higher K_2O content.

The molecular A/CNK versus A/NK diagram is used to confirm the peraluminous classification of the series (Figure 4.19). All rocks here are peraluminous, with a cluster of samples from both members of the series plotting on the peraluminous field boundary ($\text{A/CNK} = 1.1$) and one sample from each sub-division falling into the weakly peraluminous field.

4.3.3 Trace Elements

Harker diagrams for the peraluminous granitoids illustrate significant scatter with respect to some of the trace elements plotted. Given the distance between samples and variations in metamorphic grade, the scatter is not surprising. Selected high field strength elements (HFSE) and low field strength (LFSE) are plotted against silica in Figures 4.20 and 4.21.

4.3.3.1 Trace elements in the peraluminous granitoids

The trace element chemistry for the peraluminous granitoids show increasing concentrations of Y, Nb, Th and Rb with increasing silica fractionation (Figures 4.20 and

4.21) with Zr and Pb decreasing in concentration. The elements Ba and Sr show scattered results.

The PSGS has high amounts of Th (10-40 ppm), Rb (125-325 ppm), and Pb (10-50 ppm) moderate amounts of Y (5-17 ppm) and Nb (3-10 ppm). Concentrations of Ba (123-625 ppm) and Zr (50-150 ppm) range from low to moderate and Sr (50-204 ppm) is low. The PLGS has high amounts of Rb (65-210 ppm), Pb (20-45 ppm) and Sr (208-532 ppm) and moderate to high amounts of Ba (500-1450 ppm). Moderate amounts of Nb (4-15 ppm), Y (5-15 ppm) and Zr (100-175 ppm) occur within this suite along with low to moderate amounts of Th (1-19 ppm).

4.3.4 Rare earth element diagrams

All REE data for the peraluminous units have been normalized to primitive mantle values obtained from Sun and McDonough (1989) with results displayed in Figure 4.22. Patterns for the PSGS samples are generally similar. The samples have a range of $(La/Yb)_N = 30-40$ and are highly fractionated and have a wide range of REE values with $(Ce)_N = 50-75$ and one sample has an anomalously low value $(Ce)_N = 26$. Other REE concentrations show low to moderate amounts of $(Yb)_N = 1-3$, $(Sm)_N = 5-15$ and negative Eu anomalies $(Eu/Eu^*)_N = 0.4-0.9$. The biotite-muscovite-garnet±sillimanite-bearing granodiorites shows similar REE trends as the KAGS and BMGS that are displayed in Figure 4.10c.

The PLGS samples also have similar REE trends (Figure 4.22b). The samples have a range of $(La/Yb)_N = 20-50$ and are highly fractionated. Rocks here have moderate

REE concentrations with $(Ce)_N = 40-48$, $(Yb)_N = 0.5-2$, $(Sm)_N = 5-12$ and slightly negative to positive Eu anomalies $(Eu/Eu^*)_N = 0.9-1.2$.

4.3.5 Extended element diagrams

Figure 4.23 displays extended element plots for primitive mantle normalized (Sun and McDonough, 1989) values of selected REE, LFSE and HFSE. The samples analyzed are divided into PSGS and PLGS groupings, as they are in the REE diagrams.

Extended element diagrams for the PSGS are plotted in Figure 4.23a. All samples have negative Ba, Nb, Sr, P and Ti anomalies with two samples showing slightly higher Ba concentrations than the rest. Two samples in the suite show slightly positive Th anomalies and one sample displays slight K depletion. HREE's have different slopes and a fair degree of scatter but are generally depleted which is expected due to the presence of garnet in the PSGS.

Extended element diagrams for the PLGS are displayed in Figure 4.23b. All samples here show strong negative anomalies in Nb, P, and Ti with one sample showing enrichment in K and Th and a separate sample showing slight enrichment in Ba.

4.3.6 Sm and Nd isotopes

Illustrated in Figure 4.12 are $\epsilon Nd(t)$ values for the two divisions of peraluminous granite within the Committee Bay area. These samples have values similar to the potassium-feldspar-rich granodiorites and monzogranites and range from $\epsilon Nd(t)$ from

-1.40 to +0.89. The biotite-muscovite-garnet $\pm$ sillimanite-bearing granodiorites (PSGS) include four samples that have $\epsilon\text{Nd}(t)$ values that range from -1.40 to -0.42. Two biotite-muscovite-bearing monzogranitic samples (PLGS) display $\epsilon\text{Nd}(t)$ values that range from -1.11 to +0.89. The geochemical characteristics and similarities to the potassium-feldspar-rich granitoids of the Committee Bay area will be discussed further in the following section.

4.4 Chapter Summary

Geochemical data from the Committee Bay granitoids supports the presence of two major granitoid divisions within the area: metaluminous and peraluminous. Six of the eight lithological units discussed fall within metaluminous classification.

The metaluminous lithologies are then further sub-divided into the plagioclase-rich series (BTS, HBTS, and HBDS) and potassium-feldspar-rich series (BMGS, KAGS, and BMSS). The plagioclase-rich series has different abundances of not only major elements but also have markedly different concentrations of trace and rare-earth elements when compared to the granodiorite-dominant potassium-feldspar-rich series. The units that comprise the two different phases of magmatism display variable geochemical signatures as seen through A/CNK ratio, K_2O -series, ϵNd values and Ba, Zr, and Nb concentrations. A/CNK values (Figure 4.7) for the plagioclase-rich series are generally lower than those of the potassium-feldspar-rich rocks and display higher A/NK values. Several samples plot between $\text{A/CNK} = 0.85$ -1 with a cluster of BTS samples plotting in the weakly peraluminous field ($\text{A/CNK} = 1$ -1.1). BTS samples that are weakly peraluminous are likely a result of hornblende fractionation. This is due to the near-zero

A/CNK values in hornblende and any fractionation of hornblende from a granitic melt will produce residual liquid with higher A/CNK values. K_2O values for the tonalites and quartz diorites that comprise the plagioclase-rich series are lower than those for the potassium-feldspar-rich series (Figure 4.6). This is due to the variation in feldspars between the two units. K_2O wt. % values result in the plagioclase-rich series plotting in the calc-alkaline and high calc-alkaline fields while the potassium-feldspar-rich series plotting in the high-K calc-alkaline and shoshonitic fields. $\epsilon Nd(t)$ values also vary between the two feldspar series (Figure 4.24). $\epsilon Nd(t)$ values for the plagioclase-rich series range from +0.79 to +3.51 (indicating an association with more juvenile mantle component) and are different from values determined from the potassium-feldspar series which range from -2.00 to +0.16. $\epsilon Nd(t)$ values and their relation to the overall petrogenesis of the Committee Bay granitoids will be discussed in more detail in the following chapter. Geochemical differentiation between the plagioclase-rich and the potassium-feldspar-rich series rock can also be seen through their trace and rare-earth elemental abundances. Figure 4.25 illustrates trends and differences in trace element concentrations identified within the two series.

The two peraluminous units (PLGS and PSGS) also have geochemical characteristics that are distinctive from each other. Figure 4.21 shows lower concentrations of Rb and Th and higher concentrations of Sr within the PLGS. Major geochemical differences between the two can also be observed when examining the REE and extended REE element diagrams (Figures 4.22 and 4.23). REE patterns for the two peraluminous units are similar but the PSGS have a much larger negative Eu anomaly. Extended element plots demonstrate that PSGS have strongly negative Ba, Sr and P

anomalies that are not present in the PLGS. REE trends for the PLGS seem to represent primary melts that haven't undergone a lot of feldspar fractionation, as indicated by very slight to nonexistent Eu anomalies.

Figure 4.1. QAP (quartz-alkali-feldspar-plagioclase) diagram for Committee Bay granitoids. Fields are from Streickheisen (1976).

Figure 4.2. Harker diagrams showing major element variations within the Committee Bay granitoids.

Figure 4.3. Harker diagrams showing major element variations within the Committee Bay granitoids.

Figure 4.4. Total alkalis (Na₂O + K₂O) versus silica diagram. Alkaline versus sub-alkaline field boundary is from Irvine and Barager (1971).

Figure 4.5. Ternary AFM diagram for Committee Bay granitoids. FeO* was recalculated from total Fe using the method from LeMaitre (1976).

Figure 4.6. K_2O versus silica diagram for Committee Bay granitoids. Field boundaries are from Peccerillo and Taylor (1976).

Figure 4.7. Molecular $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O})$ versus $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ diagram for Committee Bay granitoids. Field boundaries are altered from Manier and Piccoli (1989). Dotted line represents beginning of peraluminous field.

Figure 4.8. Harker diagrams showing trace element compositions of the Committee Bay granitoids.

Figure 4.9. Harker diagrams showing trace element compositions of the Committee Bay granitoids.

Figure 4.10. Primitive mantle normalized REE diagram for metaluminous granitoids. Sub-divisions are based on silica content: a) 61-63 wt. %; b) 64-66 wt. % and; c) 67-72 wt. %.

Figure 4.10d. Primitive mantle normalized REE diagram for metaluminous granitoids based on silica content <60 wt. %.

Figure 4.11. Normalized extended trace element diagram for metaluminous granitoids. Sub-divisions are based on silica content: a) 61-63 wt. %; b) 64-66 wt. % and; c) 67-72 wt. %.

Figure 4.11d. Normalized extended trace element diagram for metaluminous granitoids based on silica content <60 wt. %.

Figure 4.12. Diagrams showing epsilon Nd values; a) epsilon Nd versus silica; b) epsilon Nd versus normalized (La/Sm) and; c) epsilon Nd versus normalized (La/Yb). Range of error is +/-8 epsilon Nd units.

Figure 4.13. QAP (quartz-alkali-feldspar-plagioclase) diagram for peraluminous Committee Bay granitoids. Fields are from Streickheisen (1976).

Figure 4.14. Harker diagrams showing major element variations within the peraluminous Committee Bay granitoids.

Figure 4.15. Harker diagrams showing major element variations within the peraluminous Committee Bay granitoids.

Figure 4.16. Total alkalis ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) versus silica diagram for peraluminous granitoids. Alkaline versus sub-alkaline field boundary is from Irvine and Barager (1971).

Figure 4.17. Ternary AFM diagram for peraluminous Committee Bay granitoids. FeO* was recalculated from total Fe using the method from LeMaitre (1976).

Figure 4.19. Molecular $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O})$ versus $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ diagram for peraluminous Committee Bay granitoids. Field boundaries are from Manier and Piccoli (1989).

Figure 4.20. Harker diagrams showing trace element compositions of the peraluminous Committee Bay granitoids.

Figure 4.21. Harker diagrams showing trace element compositions of the peraluminous Committee Bay granitoids.

Figure 4.22. Primitive mantle normalized REE diagram for peraluminous granitoids; a) PSGS and; b) PLGS.

Figure 4.23. Normalized extended trace element diagram for peraluminous granitoids; a) PSGS and; b) PLGS.

Figure 4.24. Epsilon Nd versus silica showing values of plagioclase-rich series (highlighted) in relation to K-feldspar-rich series.

Figure 4.25. Harker diagrams showing trace element compositions and difference in trends between the metaluminous plagioclase-rich series and K-feldspar-rich series.

Table 4.1a. Representative major element analyses for the Committee Bay granitoids.

bio-mag-bearing granodiorite suite (BMGS)

sample#	300A	1018	1207	3195	5415	1219	4177A
SiO ₂	74.83	66.61	60.53	68.48	65.47	70.19	65.46
Al ₂ O ₃	13.85	16.27	15.85	16.22	14.88	14.24	15.86
Fe ₂ O ₃	0.8	3.89	7.46	2.88	5.3	3.39	4.63
MnO	0.02	0.06	0.15	0.03	0.08	0.07	0.07
MgO	0.14	1.42	2.44	0.98	1.08	1.03	2.26
CaO	0.88	3.74	4.9	3.28	2.65	2.6	4.19
Na ₂ O	3.66	4.02	3.81	4.31	3.09	3.33	4.56
K ₂ O	5.29	3.05	3.36	2.54	4.88	4.4	1.98
TiO ₂	0.06	0.37	0.73	0.33	1.05	0.38	0.49
P ₂ O ₅	0.02	0.09	0.26	0.13	0.34	0.13	0.16

sample#	1255	CSO-187	DH0-209	1265	1269	1244	3177A
SiO ₂	68.53	72.81	65.79	73.39	72.34	72.13	73.79
Al ₂ O ₃	15.92	16.42	17.6	14.75	14.84	15.02	14.1
Fe ₂ O ₃	3.04	1.27	3.06	1.4	1.79	1.57	1.11
MnO	0.05	0.01	0.04	0.04	0.03	0.02	0.02
MgO	1.13	0.38	1.69	0.36	0.52	0.56	0.37
CaO	2.74	0.79	3.97	1.93	2.18	2.2	1.61
Na ₂ O	4.05	3.47	4.85	4.49	4.02	4.76	3.4
K ₂ O	3.78	5.45	2.05	3.31	3.81	2.84	4.89
TiO ₂	3.78	0.13	0.38	0.14	0.19	0.16	0.16
P ₂ O ₅	3.78	0.08	0.11	0.05	0.06	0.06	0.03

sample#	167	3177B	4138
SiO ₂	63.16	70.05	70.06
Al ₂ O ₃	14.3	15.56	16.19
Fe ₂ O ₃	7.151	2.3	2.08
MnO	0.08	0.03	0.04
MgO	1.3	0.75	0.67
CaO	3.7	2.03	2.73
Na ₂ O	2.86	3.82	4.99
K ₂ O	3.69	4.69	2.47
TiO ₂	1.1	0.38	0.25
P ₂ O ₅	0.39	0.04	0.07

K-feldspar augen bio-bearing granodiorite suite (KAGS)

sample#	94	281	1321	6392a	6195	HS0-239	60
SiO ₂	73.44	72.2	70.73	73.97	70.84	67.31	66.65
Al ₂ O ₃	14.53	15.26	13.87	12.16	13.41	15.8	14.23
Fe ₂ O ₃	1.66	1.68	3.48	3.1	3.258	3.3	6.41
MnO	0.02	0.02	0.04	0.03	0.04	0.06	0.09
MgO	0.44	0.52	0.92	0.44	0.47	1.96	1.14
CaO	1.92	2.09	1.55	1.3	1.38	2.52	2.79
Na ₂ O	4.14	4.46	2.68	2.41	2.3	3.04	3.04
K ₂ O	2.91	3.02	5.42	4.44	4.64	4.06	3.87
TiO ₂	0.21	0.2	0.56	0.39	0.36	0.35	0.9
P ₂ O ₅	0.05	0.06	0.2	0.18	0.07	0.12	0.29

sample#	1049	1058	1103	6195	6058	271
SiO ₂	67.65	73.2	65.09	70.84	65.13	72.43
Al ₂ O ₃	14.01	14.3	16.79	13.41	16.74	14.86

Fe2O3	6.04	1.65	5.09	3.258	3.94	1.48
MnO	0.07	0.02	0.05	0.04	0.07	0.04
MgO	1.07	0.45	1.72	0.47	1.85	0.58
CaO	2.69	1.37	3.25	1.38	4.09	1.61
Na2O	2.54	3.7	4.45	2.3	4.11	5.01
K2O	4.06	4.88	2.52	4.64	2.97	3.2
TiO2	0.89	0.23	0.48	0.36	0.41	0.19
P2O5	0.35	0.05	0.31	0.07	0.14	0.07

bio-bearing tonalite suite (BTS)

sample#	3200	4030	1301	1180	6187a	280
SiO2	67.71	69.99	68.08	67.34	72.8	72.7
Al2O3	15.37	16.03	15.42	15.72	14.68	15.16
Fe2O3	4.2	2.28	4.19	4.36	1.9	1.81
MnO	0.07	0.04	0.06	0.07	0.02	0.02
MgO	1.68	0.65	1.63	1.71	0.64	0.6
CaO	3.15	2.77	4.06	3.42	2.52	2.81
Na2O	3.55	5.12	4.66	3.63	4.46	4.6
K2O	2.99	2.1	1.3	2.71	2.33	1.47
TiO2	0.35	0.28	0.47	0.36	0.24	0.22
P2O5	0.13	0.09	0.12	0.14	0.08	0.07

hbl-bio-bearing quartz diorite suite (HBDS)

sample#	3049	2210a
SiO2	55.34	53.88
Al2O3	17.85	16.97
Fe2O3	9.69	10.37
MnO	0.12	0.16
MgO	2.96	8
CaO	6.56	7.59
Na2O	3.4	1.84
K2O	2.27	0.49
TiO2	1.14	0.71
P2O5	0.24	0.08

hbl-bio-bearing tonalite suite (HBTS)

sample#	1250	6104	1287	1332	4095	3073	285
SiO2	66.63	66.95	68.56	67.67	56.79	63.58	56.51
Al2O3	16.44	15.09	15.88	15.36	19.06	17.51	16.74
Fe2O3	3.64	5.473	2.63	3.72	7.39	5.48	8.83
MnO	0.06	0.07	0.04	0.06	0.12	0.08	0.13
MgO	1.46	1.35	1.28	1.39	3.48	1.89	3.94
CaO	3.4	2.62	2.56	3.12	6.84	5.23	6.29
Na2O	4.78	2.57	4.98	3.56	4.03	3.87	3.97
K2O	2.79	3.42	2.91	3.74	1.64	1.92	2.02
TiO2	0.38	0.65	0.37	0.33	0.65	0.44	0.88
P2O5	0.13	0.19	0.15	0.11	0.27	0.15	0.25

sample#	1306	6098
SiO2	58.23	69.49
Al2O3	16.24	15.85
Fe2O3	8.13	2.39
MnO	0.12	0.04
MgO	4.57	0.8
CaO	6.46	2.91
Na2O	3.82	4.06

K ₂ O	1.31	3.48
TiO ₂	0.8	0.23
P ₂ O ₅	0.14	0.06

bio-bearing monzogranite to syenogranite suite (BMSS)

sample#	1098	4221	4246	6145	4128	4129	49A
SiO ₂	71.87	72.48	71.65	71.38	74.15	76.49	73.53
Al ₂ O ₃	14.45	14.26	14.33	14.25	13.4	12.61	13.96
Fe ₂ O ₃	2.08	2.12	2.19	2.57	1.79	1.14	1.68
MnO	0.02	0.03	0.03	0.04	0.03	0.02	0.03
MgO	0.31	0.42	0.36	0.44	0.45	0.24	0.36
CaO	1.6	1.37	1.18	1.23	1.44	1.32	1.53
Na ₂ O	2.95	3.53	3.07	3.36	3.11	3.06	3.41
K ₂ O	5.78	5.26	6.33	5.76	4.91	4.31	4.95
TiO ₂	0.23	0.27	0.24	0.34	0.24	0.08	0.13
P ₂ O ₅	0.07	0.07	0.07	0.1	0.06	0.03	0.05

sample#	1196	1226	1134	1209	1222	1336	3176
SiO ₂	75.18	70.13	71.87	76.21	73.87	73.41	73.01
Al ₂ O ₃	13.7	14.99	15.2	12.49	13.62	13.78	14.12
Fe ₂ O ₃	0.98	2.63	1.47	1.1	1.74	2	1.63
MnO	0.02	0.06	0.02	0.02	0.03	0.05	0.03
MgO	0.19	0.75	0.68	0.31	0.43	0.26	0.36
CaO	0.67	2.04	1.98	0.9	1.36	1.32	1.39
Na ₂ O	3.8	4.03	4.52	2.95	3.39	3.91	3.38
K ₂ O	4.8	4.26	3.3	5.57	4.79	4.32	5.23
TiO ₂	0.06	0.53	0.18	0.16	0.23	0.12	0.19
P ₂ O ₅	0.02	0.12	0.06	0.03	0.06	0.04	0.07

sample#	6209	300B	183
SiO ₂	74.66	70.23	72.09
Al ₂ O ₃	14.63	15.04	14.97
Fe ₂ O ₃	0.95	3.41	1.28
MnO	0.01	0.07	0.03
MgO	0.12	1.03	0.55
CaO	1.93	2.9	1.08
Na ₂ O	3.65	3.94	5.22
K ₂ O	3.89	2.6	3.6
TiO ₂	0.06	0.31	0.16
P ₂ O ₅	0.04	0.1	0.05

bio-musc-grt+/-sil-bearing monzogranite suite (PSGS)

sample#	085c	5426	CS0-60	6392b	1317	DH0-206	JB0-196
SiO ₂	74.1	72.57	71.68	75.18	72.39	73.28	72.63
Al ₂ O ₃	14.83	14.26	15.25	13.93	14.96	16.23	15.71
Fe ₂ O ₃	1.31	2.47	1.76	1.07	1.58	0.61	1.16
MnO	0.02	0.02	0.03	0.03	0.02	0.01	0.02
MgO	0.36	0.71	0.71	0.11	0.38	0.21	0.28
CaO	1.2	1.08	1.11	1.1	0.82	0.9	0.68
Na ₂ O	3.1	2.69	3.4	3.69	2.93	3.54	4.07
K ₂ O	4.76	5.61	4.85	4.51	6.29	5.17	4.48
TiO ₂	0.23	0.37	0.21	0.06	0.21	0.04	0.11
P ₂ O ₅	0.08	0.15	0.06	0.04	0.1	0.03	0.1

sample#	6395	6396	6403	6406a	5404	DH0-208	4-49
SiO2	74.07	73.92	71.17	76.94	76.07	72.08	
Al2O3	13.99	13.97	14.62	12.66	12.1	16.3	
Fe2O3	1.7	1.92	1.76	1.23	2.57	0.65	
MnO	0.02	0.02	0.02	0.03	0.04	0.01	
MgO	0.38	0.49	0.4	0.1	1.32	0.3	
CaO	1.09	1.07	1.11	1.13	0.85	1.05	
Na2O	3.09	3.18	2.53	2.32	4.55	3.74	
K2O	5.3	5.16	6.8	5.52	1.08	4.75	
TiO2	0.23	0.27	0.23	0.03	0.25	0.04	
P2O5	0.11	0.08	0.14	0.04	0.1	0.06	

bio-musc monzogranite suite (PLGS)

sample#	1314	1341	4148	HS0-246	HS0-298	HS0-299	HS0-306A
SiO2	67.3	69.33	72.01	71.66	73.6	71.87	70.29
Al2O3	17	15.63	15.07	15.87	15.56	16.9	16.32
Fe2O3	1.86	1.855	2.21	1.4	0.62	1.32	1.66
MnO	0.02	0.02	0.04	0.04	0.01	0.01	0.02
MgO	0.62	0.49	0.8	0.43	0.33	0.75	0.57
CaO	3.43	1.91	2.12	0.8	0.58	0.94	1.08
Na2O	4.85	4.02	4.34	3.81	3.75	2.41	3.7
K2O	1.72	3.87	2.98	4.76	5.2	6.84	4.98
TiO2	0.27	0.21	0.2	0.14	0.1	0.22	0.23
P2O5	0.09	0.13	0.08	0.12	0.09	0.09	0.12

Table 4.1b. Representative trace and REE analyses for the Committee Bay granitoids

bio-mag-bearing granodiorite suite (BMGS)

sample#	3195	5415	1219	167
Ga	21	22	16	24
Ge	0.6	1.2	dl	dl
Rb	95	160	139	145
Nb	5.1	19.6	10	25
Sn	2	8	5.1	1.7
Cs	0.5	1.1	1	2.2
Ba	1,040	1,620	dl	dl
La	43.7	138	57	37
Ce	79.2	268	117	96
Eu	0.805	2.21	1.5	2
Gd	1.28	6.11	5.4	9
Tb	0.13	0.7	0.74	1.3
Dy	0.67	3.61	3.9	6.9
Ho	0.11	0.6	0.74	1.3
Er	0.3	1.62	1.9	3.4
Tm	0.041	0.2	0.32	0.49
Yb	0.26	1.2	2.1	3.1
Lu	0.037	0.163	0.34	0.46
Hf	2.9	9.6	5.2	9.9
Pb	11	29	19	21
Th	7.78	22	18	9.2
U	0.48	1.19	1.9	1.4
Sr	526	391	dl	dl
Y	3.4	17.1	23	39
Zr	103	408	dl	dl
Pr	7.78	28.5	14	13
Nd	24.7	98.3	51	57
Sm	2.84	12.4	7.7	11
Ta	0.14	1.26	0.81	1.4
W	0.5	0.5	dl	dl
Tl	0.46	1.14	0.68	0.85

K-feldspar augen bio-bearing granodiorite suite (KAGS)

4-51

sample#	94	281	1321	6392a	1103
Ga	20	21	20	18	26
Ge	0.7	0.9	1.3	1.7	dl
As	dl	dl	dl	dl	dl
Rb	79	74	163	169	142
Nb	2.4	4.2	10.8	9.3	8.5
Sn	1	3	dl	6	7.1
Cs	0.7	0.7	0.9	1.8	3.3
Ba	1,010	1,070	911	700	dl
La	39.7	26.1	63	49.4	44
Ce	72.1	53.2	129	103	93
Eu	0.921	0.868	1.08	1.15	1.5
Gd	1.12	1.65	3.38	6.74	5
Tb	0.13	0.18	0.35	0.94	0.61
Dy	0.59	0.79	1.69	4.58	3.3
Ho	0.09	0.11	0.27	0.77	0.56
Er	0.25	0.27	0.74	2.05	1.2
Tm	0.031	0.033	0.092	0.31	0.13
Yb	0.21	0.22	0.6	1.9	0.64
Lu	0.028	0.034	0.094	0.256	0.1
Hf	3.6	2.9	8.1	5.4	3.9
Pb	22	31	38	47	18
Th	3.95	8.79	34.1	20.9	9.8
U	0.53	2.3	1.18	2.46	1.5
Sr	485	510	183	124	dl
Y	2.9	3.1	8.1	21.7	17
Zr	141	100	307	195	dl
Pr	6.58	5.38	14.2	11.5	11
Nd	21.5	19.3	51.6	43.3	43
Sm	2.71	3.2	6.91	8.78	7.1
Ta	0.13	0.11	0.46	0.56	0.73
W	13.8	0.6	0.6	0.7	dl
Tl	0.48	0.48	1	1.11	0.92

bio-bearing tonalite suite (BTS)

4-52

sample#	3200	6187a	280
Ga	19	20	21
Ge	1.5	0.7	1
As	dl	dl	dl
Rb	152	88	77
Nb	8.9	4.8	7.5
Sn	3	1	2
Cs	11.2	0.9	1.9
Ba	549	713	763
La	37.4	18	22.8
Ce	71.4	31.5	44
Eu	0.888	0.723	0.926
Gd	2.95	0.96	1.25
Tb	0.42	0.12	0.16
Dy	2.18	0.62	0.82
Ho	0.39	0.11	0.14
Er	1.05	0.29	0.36
Tm	0.159	0.036	0.048
Yb	1	0.22	0.33
Lu	0.142	0.034	0.05
Hf	3.7	3.3	3.3
Pb	23	14	15
Th	11.4	4.65	4.73
U	1.69	0.52	1.53
Sr	302	342	535
Y	11.5	3	4
Zr	136	121	124
Pr	7.32	2.88	4.34
Nd	26	10.1	14.8
Sm	4.37	1.6	2.29
Ta	0.87	0.25	0.56
W	0.6	dl	0.8
Tl	0.98	0.48	0.53

hbl-bio-bearing quartz diorite suite (HBDS)

4-53

sample#	2210a
Ga	14
Ge	1.1
Rb	23
Nb	6.1
Sn	1
Cs	1.3
Ba	58
La	8.28
Ce	18.1
Eu	0.627
Gd	2.53
Tb	0.51
Dy	3.53
Ho	0.81
Er	2.54
Tm	0.442
Yb	2.94
Lu	0.454
Hf	2.2
Pb	7
Th	6.53
U	0.36
Sr	80
Y	22.6
Zr	75
Pr	2.18
Nd	9.18
Sm	2.27
Ta	0.68
W	dl
Tl	0.17

hbl-bio-bearing tonalite suite (HBTS)

4-54

sample#	6104	1306	4095	285
Ga	20	18	22	27
Ge	dl	dl	dl	1.3
As	dl	dl	dl	dl
Rb	81	62	54	73
Nb	12	6.3	6.7	6.5
Sn	dl	1.3	1.4	5
Cs	1.3	8.2	5.5	0.8
Ba	dl	dl	dl	769
La	46	12	33	37.8
Ce	100	27	73	84.3
Eu	1.4	0.89	1.7	1.5
Gd	5.6	3.1	6.74	3.7
Tb	0.91	0.52	0.88	0.5
Dy	6	3	4.32	2.6
Ho	1.3	0.64	0.7	0.5
Er	3.5	1.7	1.82	1.2
Tm	0.58	0.27	0.234	0.2
Yb	3.8	1.8	1.35	1.3
Lu	0.58	0.28	0.164	0.2
Hf	5.5	3.4	2.3	3
Pb	26	3	11	7
Th	17	1.7	3.15	3.6
U	1.9	0.37	0.27	0.47
Sr	dl	dl	517	dl
Y	39	19	19.3	15
Zr	dl	dl	87	dl
Pr	12	3.2	11.1	8.6
Nd	43	13	47	34
Sm	7.2	2.9	9.72	5.4
Ta	0.71	0.22	0.48	0.42
W	dl	0.5	dl	dl
Tl	0.87	0.39	0.38	0.34

bio-bearing monzogranite to syenogranite suite (BMSS)

4-55

sample#	6209
Ga	18
Ge	0.8
As	dl
Rb	94
Nb	2.1
Cs	0.3
Ba	1,800
La	8.69
Ce	14.5
Eu	0.874
Gd	0.48
Tb	0.07
Dy	0.34
Ho	0.06
Er	0.16
Tm	0.02
Yb	0.13
Lu	0.018
Hf	1.2
Pb	21
Th	0.63
U	0.28
Sr	534
Y	1.8
Zr	40
Pr	1.28
Nd	4.27
Sm	0.73
Ta	dl
W	0.6
Tl	0.5

bio-musc-grt+/-sil-bearing monzogranite suite (PSGS)

4-56

sample#	085c	5426	6392b	6395	6396	6403	6406a
Ga	17	20	23	18	18	16	14
Ge	1.3	1.1	0.7	0.6	1	1.5	1
Rb	110	247	225	188	206	191	149
Nb	3.1	9.4	11.9	6.5	6.3	5.7	2.2
Cs	0.6	2.7	1	1.3	1.7	0.9	0.5
Ba	459	581	169	485	523	1,000	690
La	44.3	56.5	22.2	40.7	50	23.9	6.16
Ce	91.2	125	46.7	90	105	49.3	10.2
Eu	0.614	0.663	0.384	0.535	0.65	1.06	1.23
Gd	3.88	5.47	3.09	3.73	3.61	2.87	0.82
Tb	0.55	0.53	0.5	0.39	0.32	0.35	0.26
Dy	2.8	2.26	2.97	1.63	1.38	1.64	2.28
Ho	0.5	0.36	0.61	0.23	0.2	0.26	0.56
Er	1.48	0.96	1.81	0.56	0.56	0.64	1.61
Tm	0.249	0.13	0.29	0.066	0.071	0.079	0.253
Yb	1.63	0.78	1.82	0.39	0.43	0.5	1.38
Lu	0.25	0.102	0.251	0.048	0.055	0.069	0.186
Hf	3.7	5.4	2.3	4.4	4.4	2.9	2.5
Pb	44	36	12	9	44	47	24
Th	27.9	52.2	28.7	40.3	40.1	13	1.34
U	3.51	4.17	4.68	9.64	2.58	2.83	0.45
Sr	140	118	62	113	116	168	158
Y	13.6	10.2	17.8	6.7	5.8	7.3	15.5
Zr	110	187	60	143	144	94	74
Pr	9.77	14.1	5.01	10.2	11.4	5.47	0.99
Nd	34.8	52.9	17.7	37.7	41	20.6	3.39
Sm	6.36	9.77	4.06	7.05	7.22	4.11	0.7
Ta	0.25	0.56	0.57	0.24	0.18	0.3	dl
W	0.7	0.6	0.6	0.6	0.6	0.6	0.6
Tl	0.74	1.55	0.78	0.5	1.41	1.29	0.71

bio-musc monzogranite suite (PLGS)

4-57

sample#	5404	1314	1341
Ga	16	22	23
Ge	0.5	dl	dl
Rb	29	72	168
Nb	7.7	3	6.5
Sn	2	1.1	2.3
Sb	dl	0.4	0.2
Cs	0.3	1.2	2.5
Ba	226	dl	dl
La	10.2	14	36
Ce	21.2	29	70
Eu	0.564	0.72	0.97
Gd	1.77	1.6	1.8
Tb	0.34	0.2	0.22
Dy	2.13	0.96	1.2
Ho	0.42	0.16	0.23
Er	1.2	0.32	0.72
Tm	0.189	0.05	0.12
Yb	1.19	0.26	0.74
Lu	0.174	0.04	0.1
Hf	2.8	2.8	3.2
Pb	9	9	33
Th	6.19	1.1	7.2
U	2.04	0.29	2
Sr	195	dl	dl
Y	12.7	4.5	8.3
Zr	97	dl	dl
Pr	2.38	3.1	8.3
Nd	9.5	12	30
Sm	1.92	2.2	3.9
Ta	0.81	0.13	0.51
W	1.6	dl	dl
Tl	0.14	0.49	1.1

Table 4.2. Sm and Nd isotopic analyses from the Committee Bay granitoids.

sample #	age (Ga)	$^{143}\text{Nd}/^{144}\text{Nd}$	2σ	$^{147}\text{Sm}/^{144}\text{Nd}$	$^{143}\text{Nd}/^{144}\text{Nd}$ (t)	$\epsilon\text{Nd}(t)$
K-feldspar augen bio-granodiorite suite (KAGS)						
1321	2.61	0.51057	16	0.0771	0.50925	-0.04±0.8
bio-tonalite suite (BTS)						
280	2.61	0.51088	17	0.0874	0.50925	2.57±0.8
CS0-296	2.718	0.51105	20	0.0984	0.50929	3.51±0.8
3200	2.61	0.51101	23	0.1002	0.50925	0.79±0.8
hbl-bio-tonalite suite (HBTS)						
HS0-289a	2.61	0.51071	20	0.08	0.50934	1.75±0.8
hbl-bio-quartz diorite suite (HBDS)						
2210a	2.58	0.51184	13	0.1426	0.50929	2.42±0.8
bio-monzogranite to syenogranite suite (BMSS)						
6209	2.58	0.51084	18	0.0937	0.50929	-0.42±0.8
1341	2.58	0.51083	19	0.0902	0.5093	0.16±0.8
6195	2.58	0.51117	16	0.1129	0.50925	-0.75±0.8
bio±mag-granodiorite suite (BMGS)						
167	2.61	0.51139	18	0.1306	0.50918	-2.00±0.8
bio-musc-grt±/-sil granodiorite to monzogranite suite (PSGS)						
85	2.58	0.51106	20	0.1087	0.50929	-1.40±0.8
6395	2.58	0.51098	19	0.1031	0.50929	-1.40±0.8
HS0-306a	2.58	0.51072	20	0.0856	0.50927	-0.42±0.8
bio-musc monzogranite (PLGS)						
1314	2.58	0.51112	20	0.1053	0.50934	0.89±0.8
HS0-298	2.58	0.51104	19	0.1061	0.50923	-1.11±0.8

CHAPTER 5: PETROGENESIS OF THE COMMITTEE BAY GRANITOIDS

5.1 Introduction

Several processes have contributed to the magmatic evolution and plutonism of the Committee Bay area. These processes potentially include assimilation, fractional crystallization, magma mixing/mingling, and crust-mantle interaction. The mantle is a dynamic geochemical environment and includes mantle end-members that must be considered. Such end-members include: a depleted-asthenospheric mantle; an enriched subcontinental lithospheric mantle and; a subduction related modified depleted mantle. Besides mantle source contributions, another important magma generating event to be considered is *in situ* crustal melting of sedimentary or other crustal protoliths that can generate granitic melts.

It is important to systematically evaluate all the processes that have played a significant role in the petrogenesis of these granitoids. The processes mentioned are complex and even more so when combined. The following describes the magmatic evolution processes and how they apply to the three series that comprise the Committee Bay granitoids. These series are; a tonalitic series; a granodioritic/monzogranitic series and; a peraluminous granitoid series. Field evidence in the study area indicates a tectonic setting characterized by extrusion of komatiitic lavas. The movement of ultramafic magmas through the crust from the mantle likely contributed to the heat source that led to the melting of lithospheric components. The heat input was enough to trigger an episode of dehydration melting of an amphibolitic source that led to the production of intermediate to felsic magmas and subsequent intrusion of the tonalitic series. This event was followed by an episode of lower- to mid-crustal *in situ* melting/migmatization that

produced a bloom of metaluminous, intermediate to felsic intrusions as well as scattered peraluminous granitic pods and dykes. These events will be discussed in further detail below.

5.2 Petrogenesis Of The Tonalite Series

5.2.1 The role of fractional crystallization

The tonalitic series is the oldest granitoid unit in the Committee Bay belt and potentially has the most to reveal about source regions and processes involved in Committee Bay plutonism. This series has the broadest range in silica content (51-73 wt. %) and is comprised of biotite-bearing tonalite (BTS), hornblende-biotite-bearing tonalite (HBTS), and lesser volumes of biotite-hornblende-bearing quartz diorite (HBDS). The Nd isotopic data for the series is quite consistent with 4 out of five samples plotting between $\epsilon\text{Nd}(t) = +1.75 - +3.51$, values that are consistent with an upper mantle or juvenile crustal source. These samples were collected over a range of 250 km.

The tonalitic series has undergone liquid crystal fractionation. Evidence of this is supported by whole rock compositional chemistry and the existence of intermediate and felsic end-members. The major fractionating mineral phase in this series is hornblende. With increasing silica content the amount of fractionation within the tonalitic series increases. Figure 5.1a displays REE trends of differentiated samples that are grouped by silica content (<60 wt. %, 61-63 wt. %, 64-66 wt. %, 67-72 wt. %). With increasing differentiation the amount of LREE's increase and MREE and HREE concentrations decrease. This type of REE fractionation is characteristic of hornblende fractionation

(Sakwa, 1988). Figure 5.1a illustrates LREE patterns of less differentiated samples crossing over the LREE patterns of those samples with higher silica content.

Hornblende fractionation has a tendency to absorb REE's selectively and as a result we see a variety of REE concentrations within the same series. Major elements that provide evidence of hornblende fractionation are Al_2O_3 , Na_2O , K_2O and CaO (Figure 5.1b). Semi-qualitative modelling of hornblende fractionation using the dacitic K_d 's of Arth 1976) are shown in Figure 5.1c. The REE pattern for the magmas with a silica range between 61-63% was used as starting compositions and the 10% and 20% fractionation patterns for hornblende were produced. The REE patterns produced results similar to those of the 61-63 wt. % silica range for the plagioclase-rich series. These results show that hornblende is a major fractionation phase and has had significant effects on the REE signatures. Figure 5.1d illustrates A/CNK increasing with increasing silica content. As hornblende fractionates from a melt its low A/CNK value results in residual liquids having higher A/CNK values. Low A/CNK values in Figure 5.1b are associated with samples bearing hornblende (HBDS and HBTS) while the weakly peraluminous samples (higher A/CNK values) are those that lack hornblende (BTS).

5.2.2 Generation of the parental magmas

The majority of samples collected from the tonalite series range from $\epsilon\text{Nd}(t) = +1.75$ to $+3.51$. Lithologies in the series range from intermediate quartz diorites to more quartz-rich, tonalitic end-members. The intermediate units in the series are in low volume throughout the study area but display similar geochemical signatures and very similar $\epsilon\text{Nd}(t)$ values to the more felsic end-members. For example, the quartz diorites

have similar low values of Ba and K_2O , negative Sr anomalies and high $\epsilon Nd(t)$ values (+2.42). High MgO values are also characteristic of the intermediate samples and indicate their association with a mafic component.

It is very likely that upon intrusion of tonalitic magmas that a crustal component was assimilated within the melt. This is evident when observing the field characteristic of the series end-members. In the field the tonalite series contain distinctive xenolithic fragments that are psammitic and pelitic in composition. The assimilation of these xenoliths altered the geochemistry of the unit, in particular the Nd isotopic signature. With an increased amount of assimilated metasediments the Nd isotopic signature of the rock has a tendency to decrease. In the case of the Committee Bay tonalitic series the amount of assimilated material is not enough to significantly alter the units and the depleted mantle Nd isotopic signature is still preserved (Figure 4.24).

The intrusion of the tonalitic series occurred syn- to post-extrusion of the ultramafic lavas. Komatiitic magmas acted as the heat source for the production of the tonalitic series melts. During the ascent of the hot ultramafic magmas, large volumes of amphibolite from the lower crust were re-melted and dehydrated to produce melts that were tonalitic in composition. Upon emplacement, the tonalitic melts assimilated materials from the mid- to shallow-crust such as metasedimentary quartzite and semi-pelite.

5.3 Petrogenesis Of The Granodioritic/monzogranitic Series

5.3.1 The role of fractional crystallization

The granodioritic/monzogranitic series, like the tonalitic series, is a voluminous division of the Committee Bay plutonic event and key in interpreting the magmatic history of the area. This series has a broad range in silica content (60-77 wt. %) and is comprised of potassium-feldspar augen granodiorite (KAGS), potassium-feldspar megacrystic granodiorite (BMGS), and lesser volumes of biotite-bearing monzogranite and syenogranite (BMSS). The Sm-Nd isotopic data for the series are consistent with 4 out of five samples plotting between ($\epsilon\text{Nd}(t) = -2.0$ to -0.04). These samples were collected over a range of 200 km.

The granodioritic/monzogranitic series, like the tonalitic series, has undergone liquid crystal fractionation. The main fractionating phases in this series are feldspars. With increasing silica the amount of fractionation within the series increases. Figures 5.2a, and b display REE trends of differentiated samples that are grouped by silica content (61-63 wt. %, 64-66 wt. %, 67-72 wt. %). With increasing silica content the amount of MREE and HREE concentrations decrease. The REE patterns also display negative Eu anomalies which are likely a product of feldspar fractionation.

Figure 5.2c is a logarithmic plot of Ba versus Sr for the granodiorite/monzogranite series. The vectors on the right side of the diagram represent 40% fractional crystallization of plagioclase-feldspar, potassium-feldspar, biotite and hornblende (Fumerton *et al.*, 1984). Samples from the series plot such that a trajectory is formed that resembles what is expected for potassium-feldspar fractionation. The diagram displays both Ba and Sr decreasing with increasing silica content. This trend suggests that potassium-feldspar was an important fractionation phase involving

granodioritic samples with intermediate wt. % silica values and monzogranitic/syenogranitic samples with high wt. % silica values.

5.3.2 Generation of the parental magmas

The majority of samples collected from the granodiorite/monzogranite series range from $\epsilon\text{Nd}(t) = -2.0$ to -0.04 . Lithologies in the series vary from intermediate granodiorites to felsic monzogranites and syenogranites, all of which contribute largely to the total volume of Committee Bay granitoids.

The NMS hosts a large volume of migmatized metasediments derived from the Committee Bay supracrustal sequence. Migmatitic units in the domain have similar Nd isotopic signatures to the granodiorite/monzogranite series and leucosomatic portions of the migmatites have whole rock chemistry and $\epsilon\text{Nd}(t)$ values that is comparable to that of the felsic end-members of the series. Thus, evidence points to a crustal melting origin for the granodiorite/monzogranite series.

Upon ascent from low-crustal levels into the shallow crust, magmas from the granodiorite/monzogranite series engulfed xenoliths of older crust. Evidence of the xenolithic inheritance was identified in the field as inclusions of semi-pelitic and pelitic material.

5.4 Petrogenesis Of The Peraluminous Series

5.4.1 Generation of parental magmas

The peraluminous leucogranites (PLGS) and classic “S-type granites” (PSGS) exposed in the Committee Bay area are products of partial melting within the mid- to

lower crust at ca. 2.61 Ga. Tectonic processes that led to the production of the peraluminous melts are similar to those from which the granodiorite/mongranite series evolved. Figure 5.3 displays Sm-Nd isotopic data for the peraluminous granites and compares them with the granodioritic/monzogranitic series and the Committee Bay migmatites.

Peraluminous leucogranites are the only granitic rocks that are undoubtedly pure crustal melts. They form by dehydration-melting of muscovite-rich metapelitic sources, most likely during fast adiabatic uplift and decompression of thickened crustal orogens (Patino Douce, 1999). This statement is further supported in the Committee Bay area through petrographic and geochemical observations. Figures 5.4a displays REE patterns for the PLGS indicating very slight negative Eu anomalies ($\text{Eu}/\text{Eu}^* = 0.85\text{-}0.88$), a result of only minor feldspar fractionation. Petrological observations of this unit show that the rock is homogeneous and equigranular and shows very little evidence of xenocrystic contributions. The only evidence of xenocrystic material within the PLGS occurs in the form of inherited zircons which yielded an imprecise crystallization age when analyzed via SHRIMP (Carson, *personal communication*). This is a result of incomplete melting of source rocks and the slow melting character of zircon.

The PSGS unit has textural and field characteristics similar to those of the granodiorites of the granodioritic/monzogranitic series. The exception is, of course, the presence of aluminous minerals such as muscovite, garnet +/-sillimanite. Geochemical data also suggest that the PSGS unit is more closely linked to the granodioritic/monzogranitic suite. Figure 5.4b displays extended REE patterns for a sample of the PSGS, a metaluminous granodioritic sample of similar silica content, and a

PLGS sample. Note the similarities in extended REE patterns between the metaluminous granodiorites and the PSGS, in particular the similarities in Th enrichment and P and Sr depletion. As mentioned in chapter 3, textural similarities also exist between the PSGS and metaluminous granodiorite. This is evident when observing primary crystallization features of the feldspars, such as granophyres and cross-hatch twins. The PSGS does not possess the same petrological and geochemical characteristics as the PLGS and the magmatic evolution and formation of the PSGS was likely associated with assimilation of alumina-rich metasediments during the emplacement of a granodioritic pluton derived from the granodioritic/monzogranitic series.

5.5 Tectonomagmatic Summary Of Granitoid Magmatism Within The Committee Bay Belt

The origin of the tonalitic series involves the dehydration-melting of an amphibolitic source rock as a result of crustal heating caused by the ascent of ultramafic magmas ca. 2.72 Ga.. Sm-Nd isotopic geochemistry yields $\epsilon\text{Nd}(t)$ values ranging between +1.75 to +3.51. These values obtained from the tonalitic series suggest its derivation from a juvenile mafic source (Figure 5.5). Concentrations of Rb, Zr, LREE's and K_2O combined with the $\epsilon\text{Nd}(t)$ signatures suggests that relative enrichment in LREE's was likely due to assimilation of older crust (Figure 5.6).

Following the formation of the tonalitic melts and heating of the lithospheric crust ca. 2.61 Ga, an episode of metasedimentary partial melting and magma assimilation occurred in the low- to mid-crustal level. The assimilation of the metasedimentary component with the more evolved tonalitic melts produced a series of intermediate melt

compositions that were granodioritic in character. Ascent, fractionation and emplacement of these magmas occurred ca. 2.61-2.58 Ga and resulted in the formation of granodioritic plutons followed by later intrusion of monzogranitic and syenogranitic plutons. Within this time bracket an intrusive event involving two types of peraluminous granitoids also occurred. The PSGS, or classic “S-type” granite, formed as a result of partial melting and magmatic assimilation of alumina-rich sediments by the intermediate magmas responsible for the formation of the granodiorite/monzogranite series. The second peraluminous phase comprised of two-mica leucogranites (PLGS) evolved and crystallized under different conditions than those responsible for the formation of the PSGS. Although no precise crystallization age has been determined for the peraluminous leucogranites of the Committee Bay region, their emplacement is assumed to have occurred between 2.61 –2.58 Ga during fast adiabatic uplift and decompression of thickened continental crust.

Figure 5.1. a) normalized REE diagram showing increase in LREE fractionation with respect to increasing silica in the plagioclase-rich series; b) molecular $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O})$ versus $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ diagram for the plagioclase-rich series; c) 10-20% hornblende fractionation using 61-63 wt% silica average as starting material(dashed line) and; d) SiO_2 wt. % versus $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$.

Figure 5.2. a) extended REE diagram showing increased fractionation of units in the granodioritic/monzogranitic series with respect to increasing silica wt. %; b) REE diagram of silica end-members in the granodioritic/monzogranitic series; c) logarithmic plot of Ba versus Sr showing K-feldspar fractionation trend.

Figure 5.3. Epsilon Nd versus SiO_2 displaying similarities in epsilon Nd signature between granodioritic/monzogranitic series, PLGS, PSGS, and migmatites.

Figure 5.4. a) REE diagram showing negative Eu anomalies in PSGS and flat Eu trends in PLGS and; b) extended trace element diagram comparing/contrasting ranges in Th and P between PLGS, PSGS and metaluminous granodiorite.

Figure 5.5. Diagram showing $\epsilon_{\text{Nd}}(t)$ versus age (Ga) for Committee Bay granitoids and komatiites. Depleted Mantle evolution curve is calculated from $\epsilon_{\text{Nd}}(t) = 8.6 - 1.91(t)$ where (t) is age (DePaolo *et al.*, 1991). Komatiite values from Machattie (*personal communication*).

Figure 5.6. Cartoon depicting the Late Archean evolution of the Committee Bay region; a) ca. 2.72 Ga development of late ultramafic volcanism and intermediate to felsic magmatism as a result of dehydration melting of amphibolitic source rocks; b) ca. 2.72-2.61 Ga plutonism during which some quartz dioritic and tonalitic melts are emplaced while others continue to assimilate older crust and evolve and; c) ca. 2.61-2.58 Ga crustal melting/migmatization of sediment package at low- to mid-crustal levels assimilating with previously formed melts creating metaluminous granitoids followed by peraluminous melt formation as the result of fast adiabatic uplift and decompression.

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APPENDIX A: ANALYTICAL METHODS

A.1. GEOCHEMICAL SAMPLING AND PREPARATION

All geochemical data in this study was collected from samples taken during three summers of mapping in the Committee Bay region. Samples collected in the field were selected based on their degree of alteration and weathering and only those with the least amount were chosen. Samples selected for lithogeochemical work were generally on the order of 5-10 kg in total.

All samples were crushed in a jaw crusher upon arrival at Carleton University. This reduced the samples to <1 cm chips that were then placed in a chrome-steel ring and puck assembly and milled until a fine powder was formed. Prior to powdering the ring mill was pre-contaminated with small portions of each sample being powdered. The powders produced were approximately 200 μm mesh size. In order to collect a representative sample this procedure was repeated several times for all samples and much larger volumes of powder than necessary were produced. The powders were then mixed to homogenize the sample. Between 50-75 g of sample was then transferred to a vial for use in geochemical analyses.

A.2. X-RAY FLUORESCENCE (XRF)

Twelve of the selected samples were analyzed by means of X-ray fluorescence at the Department of Earth Sciences at University of Ottawa. The major elements SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3 , MnO , MgO , P_2O_5 , Na_2O , K_2O and CaO were determined by a fused disc technique.

A.2.1. Fused-disc method for major element analysis

An approximately 3:1 flux to sample ratio was added to a porcelain crucible and then heated to approximately 1200°C. The resultant liquid was then poured into a platinum, disc-shaped mould and allowed to cool. This procedure produces smooth, approx. 35mm, homogeneous glass discs ready for analysis in the XRF. An automated computer system connected to the XRF was used in data collection. The data reduction was performed with an in-house written program and was carried out using a PC and spreadsheet software.

A.3. INDUCTIVELY COUPLED PLASMA MASS SPECTROMTRY (ICP-MS)

Selected trace elements (Y, Th, La, Ce, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu) were analysed on a HP 4500 inductively coupled plasma mass-spectrometer. These samples were prepared by the Na₂O₂ sinter method. This method was chosen because of its ability to dissolve refractory minor phases, such as zircon, which are commonly found in these types of rocks. These refractory phases commonly house the majority of the HFSE and REE, which are difficult to decompose using the HF(aq) procedure. A 0.2 g sample of rock powder is accurately weighed and combined with 0.8 g of Na₂O₂ in a nickel crucible. The crucibles are then placed in a furnace and sintered for 1.5 hours at 500°C. The samples are then removed and cooled for about 20 minutes. Once cool, 10 ml of distilled water is added and the mixture is then poured into a centrifuge tube. Distilled water is then added to make a total volume of 30 ml in the centrifuge tube and the sample is centrifuged for approximately 15 minutes. The liquid is poured off and the residue is rinsed with 25 ml of distilled water, the rinse and centrifuge procedure is then

carried out one last time. The residue is then dissolved in 2.5 ml of 8M HNO₃ and 4 ml of oxalic acid. The crucible is then rinsed with 0.2M HNO₃ and added to the centrifuge tube and left overnight. The next day 4 ml of 0.11M HF/0.453M boric acid solution is added and the solution is desiccated in the drying oven for 2 hours. The solution is then transferred to a clean jar and made up to 50 g with distilled water. Before the solutions are run on the ICP-MS they must be diluted. To dilute the sample, 2 g of sample solution is added to 8 g of 0.2M HNO₃ in a test tube.

During runs on the ICP-MS the samples are also run with: 1) a quartz reagent; 2) a sample duplicate and; 3) a standard.

A.4. ISOTOPE DILUTION PROCEDURE FOR THE ANALYSIS OF SAMARIUM AND NEODYMIUM

Sm and Nd isotopic measurements were conducted on 15 selected granitoid samples for the purposes of this study. Sm and Nd isotopic compositions were analysed by thermal ionization mass spectrometry (TIMS) using the isotope-dilution preparation technique outlined by Cousens (2000). Between 100 and 200 mg of sample was added to a Teflon beaker and spiked with a mixed ¹⁴⁹Sm-¹⁴⁸Nd spike solution. The samples were then dissolved in with 50% hydrofluoric acid- 16N nitric acid, then 8N nitric acid and finally 6N hydrochloric acid. The sample was then allowed to reflux for a period of 24-48 hours. Initial separation of the REE was completed by loading the samples onto BioRad cation resin. The resin retains the REE while removing the major and trace elements. The collected fractions were then dried down and dissolved in 0.26N hydrochloric acid. The dissolved fractions were then pipetted into a columns containing

a 2 cm-high bed of Teflon powder coated with HDEHP (di(2-ethylhexyl) orthophosphoric acid [Richard *et al.*, 1976]). Nd was eluted using 0.26N hydrochloric acid. All samples were run on a Finnigan-MAT 261 thermal ionization mass spectrometer in the static mode. Nd was loaded with HCl(aq) on one side of a Re double filament assembly. Isotope ratios are normalized to $^{146}\text{Nd}/^{144}\text{Nd} = 0.72190$. Analyses of the La Jolla standard average $^{143}\text{Nd}/^{144}\text{Nd} = 0.511874 \pm 19$ (n=23). Measured Sr and Nd isotope ratios in the SRM987 and the La Jolla standards correspond closely to those obtained by other laboratories, and no correction to measured ratios in the samples was necessary.

APPENDIX B: PRIMITIVE MANTLE NORMALIZATION VALUES USED

"Sun/McDon. 1989-PM", "Primitive Mantle normalization values"

Element	Normalization value
Rb	0.635
Ba	6.989
K	250
Th	0.085
Nb	0.713
La	0.687
Ce	1.775
Pr	0.251
Sr	21.1
Nd	1.354
Zr	11.2
P	95
Sm	0.444
Eu	0.168
Tb	0.0974
Ti	1300
Gd	0.596
Dy	0.737
Ho	0.148
Er	0.480
Tm	0.0676
Y	4.55
Yb	0.493
Lu	0.074

"Wood *et al.*, 1979", "Primordial Mantle normalization values"

Element	Normalization value
Cs	0.019
Rb	0.860
Ba	7.560
Th	0.096
U	0.027
K	252.0
Ta	0.043
Nb	0.620

La	0.710
Ce	1.900
Sr	23.000
Nd	1.290
P	90.400
Hf	0.350
Zr	11.000
Sm	0.385
Ti	1200
Tb	0.099
Y	4.870

APPENDIX C: PARTITION COEFFICIENTS USED

“Arth, 1976”

Element	Partition coefficient value for hornblende
Rb	0.014
Sr	0.22
Ba	0.044
Ce	0.899
Nd	2.890
Sm	3.990
Eu	3.440
Gd	5.480
Dy	6.200
Er	5.950
Yb	4.890
Lu	5.430