EARLY PROTEROZOIC GRANITOID MAGMATISM AND CRUSTAL EVOLUTION IN THE MAKKOVIK PROVINCE OF LABRADOR: A GEOCHEMICAL AND ISOTOPIC STUDY

ANDREW KERR, B.Sc., M.Sc.

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30, and subsequent amendments.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30, et ses amendements subséquents.

Canada

EARLY PROTEROZOIC GRANITOID MAGMATISM AND CRUSTAL EVOLUTION IN THE MAKKOVIK PROVINCE OF LABRADOR: A GEOCHEMICAL AND ISOTOPIC STUDY

by

©   Andrew Kerr, B.Sc, M.Sc.

A thesis submitted to the School of Graduate
Studies in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

Department of Earth Sciences
Memorial University of Newfoundland

June, 1989

St.John's
Newfoundland
CANADA

ISBN 0-315-65315-9

THREE PERSPECTIVES ON THE ORIGIN AND
INTERPRETATION OF GRANITES

"Field studies of granites deal with end products of processes long since completed, and the most detailed mapping and study of these products may fail to give convincing evidence concerning the exact nature of the processes responsible for the relations."

From :   **O.F.Tuttle and N.L.Bowen, 1958.** *Origin of granite in the light of experimental studies in the system* $NaAlSi_3O_8 - KAlSi_3O_8 - SiO_2 -H_2O$.

From the book that ended the "granite controversy", and laid the foundations for most current thought on silicic magmatism.

"The road to understanding orogenic processes, particularly in Precambrian terranes, is littered with misused discriminant diagrams and the hope of a simple link between the trace element compositions of igneous rocks and tectonic environment."

From: **C.J.Hawkesworth, M.A.Menzies and P. van Calsteren, 1986.** *Geochemical and tectonic evolution of the Damara Belt, Namibia.*

From a symposium on collision tectonics, organized by the Geological Society of Great Britain.

"I would certainly hope that 100 years hence, we will not be debating the origins of granites!"

From: **W.S.Fyfe, 1988.** *:ranites and a wet convecting ultramafic planet.*

From a conference on the origin of granites, organized by the Royal Society of Edinburgh to commemorate the bicentennial of James Hutton.

Thesis Abstract

The Lower to Middle Proterozoic Trans-Labrador Granitoid Belt in the Makkovik Structural Province is divided on the basis of field relationships and geochronology into *Makkovikian* and *Labradorian* plutonic assemblages, representing approximate time intervals of 1840 - 1720 and 1670 - 1600 Ma respectively. The Makkovikian assemblage includes both syn- and post-tectonic associations, but precise U-Pb zircon ages mostly cluster around 1800 Ma, suggesting a single main intrusive episode that transcended the later deformation associated with the Makkovikian orogeny. The Labradorian assemblage is not associated with local deformation or metamorphism, but is probably a distal effect of the ca. 1650 Ma Labradorian orogeny, prevalent south of the study area. Both assemblages are broadly correlative with volcanic sequences of similar age and geochemical affinity.

The Makkovikian assemblage is dominated by siliceous, potassic, commonly porphyritic, granites and alkali-feldspar granites, associated with subordinate monzonite to quartz syenite. High-silica granite suites are commonly fluorite-bearing. In geochemical terms, most Makkovikian granitoids are metaluminous to slightly peralkaline, Fe-enriched, and enriched in Zr, Nb, Hf, REE, Zn and fluorine. A comparative analysis suggests that they are transitional in character between Phanerozoic post-orogenic (post-collisional) assemblages and "A-type" or "within-plate" granitoid assemblages. Similarly enigmatic characteristics have been reported from Early Proterozoic granitoid batholiths elsewhere in the world.

The subordinate, bimodal, Labradorian plutonic assemblage comprises gabbro-diorite-monzonite-syenite suites, derived from mafic parental magmas, and an assortment of siliceous, generally leucocratic, granitoid rocks. Mafic rocks resemble high-K calc-alkaline or shoshonitic basalts, and their associated felsic differentiates are enriched in Rb, Cs, Th, and U, as a consequence of protracted fractionation. Other Labradorian granites (s.s.) are metaluminous to peraluminous in composition, and depleted in Zr, Nb, Hf, REE, Zn and fluorine, indicating that they had quite different sources from their Makkovikian counterparts.

The Makkovikian assemblage displays geographically systematic Nd isotopic variations. In the west, negative ϵ_{Nd}CHUR indicates ancient (probably Archean) crustal material in sources, but values are too high to permit derivation *entirely* from such material. These rocks probably represent mixtures of juvenile, mantle-derived, magma and older polycyclic Archean crust. In the east, positive ϵ_{Nd}CHUR indicates juvenile, Proterozoic sources, and gneissic rocks representing possible basement have depleted-mantle Nd model ages of ca. 2100 Ma. Discrete, high-silica, "A-type" granite plutons show an east-west shift in

ϵ_{Nd}CHUR from +6 to -6, but retain remarkably similar *elemental* characteristics in both domains. It is concluded that magmas in the east also contained a significant crustal component, but that this component had a short crustal residence period. Nd isotopic data thus define a fundamental crustal boundary between an Archean Craton and a younger (accreted?) Proterozoic crustal province. Makkovikian magmatism accompanied and followed accretion of the younger domain, and is suggested to have resulted from emplacement of anhydrous, hot, mantle-derived mafic magmas into the lower crust, where they crystallized, assimilated and mixed with crustal rocks and melts thereof.

Labradorian rocks mostly have ϵ_{Nd}CHUR of +1 to -2, regardless of composition or location. Olivine-bearing mafic rocks, which cannot represent crustally-derived magmas, have ϵ_{Nd}CHUR of ca. +1, significantly below postulated values for concurrent depleted mantle. It is suggested that this crustal component was introduced to depleted mantle via subduction of continent-derived sediment, as suggested for modern arc magmas. However, some Labradorian granites that lack mafic parents could be derived by anatexis of Makkovikian "mixed" crust, or juvenile material underplated during Makkovikian events. Labradorian magmatism is tentatively interpreted as a distal-arc assemblage above a subduction zone that records renewal of tectonic activity following Makkovikian terrane accretion and magmatism.

The isotopic characteristics of both assemblages underline the importance of the Early Proterozoic as a period of new crustal growth. Makkovikian magmatism *reorganized* previously generated crust, and added significantly to it, particularly in the "juvenile" eastern domain. Largely *ensialic* crustal growth of this type may have been more important in a hotter, Proterozoic Earth and, in concert with ensimatic crust generation linked to subduction, may account for the high crustal growth rates deduced for this crucial period in planetary evolution.

The transitional characteristics of the Makkovikian assemblage may also be a function of greater heat flow. Recent models for "anorogenic" magmatism invoke insulation of the mantle by newly-accreted crust or aggregated megacontinents, resulting in mantle upwelling, plume activity, magmatism and (eventually) rifting. In a hotter Proterozoic Earth, the time-lag between aggregation and mantle upwelling would be shorter, and conditions now associated with "anorogenic" magmatism would prevail widely in post-orogenic environments. It is perhaps significant in this respect that worldwide Lower Proterozoic (1900 - 1700 Ma) orogenic events have recently been interpreted to record the assembly of an early Pangean-type supercontinent.

KEY WORDS : Labrador, Precambrian Proterozoic, Granitoids, Granite, Batholiths, Petrology, Geochemistry, Comparative, Isotopes, Neodymium, Petrogenesis, Crustal Evolution.

Acknowledgements

The only portion of writing a Ph.D. thesis that I can truly describe as *pleasurable* is acknowledging the many people whose support, encouragement and direct assistance enabled me to overcome periodic disillusionment and frustration, and complete this seemingly endless task.

My greatest debt is to my wife Vi, whose love, support and patient understanding, whilst our lives were disrupted by the demands of this project, continues to amaze me and remind me of my good fortune. I dedicate this tome to her, for enduring all this nonsense with such grace and go·d humour.

The Geological Survey Branch of the Newfoundland Department of Mines (NDM) provided the logistical and technical support that made a project of this type feasible within the framework of a government geoscience survey. I acknowledge this vital assistance, and also their constant encouragement of scientific research, discourse and innovation in all their employees. Tom Krogh's U-Pb zircon geochronology built the framework within which geochemical data were interpreted, and I thank him sincerely for his interest and assistance.

Derek Wilton initially suggested this project, and is therefore responsible also for my current position at NDM, for which he certainly deserves more than mere acknowledgement ! He offered sound advice, assistance and prompt constructive criticism throughout, and continues to do so. Brian Fryer served as chairman of my commitee, and is thanked for his unusually prompt reading of earlier drafts, and valuable insight into isotope geochemistry anc the black art of mass spectrometry. My external committee member, Charlie Gower (NDM), provided incisive and detailed

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER EIGHT : ISOTOPE GEOCHEMISTRY

CHAPTER 9 : A COMPARATIVE ANALYSIS

LIST OF PLATES

General Acronyms

TLGB - Trans-Labrador Granitoid Belt
MUN - Memorial University of Newfoundland
NDM - Newfoundland Department of Mines
BRINCO or BRINEX - British Newfoundland (Exploration) Corporation
GSC - Geological Survey of Canada
MASH - Melting, Assimilation, Storage and Homogenization (process)
VAG - Volcanic Arc Granite
ORG - Ocean Ridge Granite
WPG - Within-Plate Granite
COLG - Collisional Granite
MORB - Mid-Ocean Ridge Basalt

Geochemical Acronyms

REE - Rare Earth Elements
HFS - High Field Strength (Elements)
LFS - Low Field Strength (Elements)
OCC - Octahedrally Co-ordinated Cation (Elements)
CHUR - Chondritic Undepleted (or uniform) reservoir
DM - Depleted Mantle
AAS - Atomic Absorption Spectrophotometry
ICP-ES - Inductively-Coupled Plasma Emission Spectrometry
ICP-MS - Inductively-Coupled Plasma Mass Spectrometry
NAA - Neutron Activation Analysis
XRF-ES - X-Ray Fluorescence (Emission Spectrometry)
ISE - Ion-selective Electrode (analysis)

Geochemical Parameters

FeOt (FeO* in diagrams only) - Total iron as FeO
Fe_2O_3t - Total iron as Fe_2O_3
A/C+N+K (alumina index) $\cong$ molecular $[Al_2O_3/(CaO+Na_2O+K_2O)]$
K+N/A (agpaitic index) = molecular $[(K_2O+Na_2O)/Al_2O_3)]$
F/F+M = FeOt / (FeOt + MgO)
N/N+K = Na_2O / (Na_2O + K_2O)
N (subscript, as in La_N, or La* in some diagrams) - normalized to
    chondritic value

Mineral Abbreviations (Descriptive Tables)

Px - pyroxene	Opx - orthopyroxene	Cpx - clinopyroxene	Ae - aegirine
Hb - hornblende	Act - Actinolite	Bi - biotite	Chl - chlorite
Ol - olivine	Fa - fayalite	Ep - Epidote	Sph - sphene
Zr - zircon	Ap - apatite	All - allanite	Fl - fluorite
Qz - quartz	Ms - muscovite	Plag - plagioclase	Fsp - feldspar
Fe-Ox - iron oxide		K-fsp - potash feldspar	

Mineral Abbreviations (CIPW Normative Minerals)

Q - quartz	C - corundum	Or - orthoclase	Ab - albite
An - anorthite	Di - diopside	Hy - hypersthene	Ol - olivine
Mt - magnetite	Il - Ilmenite	Ne - nepheline	

Measurement Units

If units are not specified in geochemical graphs or charts, it can be
assumed that major element oxides and normative minerals are
expressed as weight percent, and trace elements as weight parts per
million (grams/Tonne).

CHAPTER ONE
INTRODUCTION

1.1 PROJECT OVERVIEW

Proterozoic Magmatism and Crustal Evolution

Sir Charles Lyell (1885) established the framework for most geological thought with his *principle of uniformitarianism*. Although this concept of the present as the key to the past remains a cornerstone of our science, some of the broader applications of Lyell's doctrine are actively debated by geoscientists who study the Precambrian.

The Proterozoic Eon, extending from 2500 Ma to 570 Ma ago, is the longest segment of Earth history for which the geological record is complete. This vast period is the best vehicle for testing concepts of long-term uniformitarian (e.g. Windley, 1983), unidirectional (e.g. Dickinson, 1981) or cyclic (e.g. Sutton, 1963; Hoffman, 1989) evolution of the Earth.

There is now general agreement that mobile lithospheric plates existed throughout the Phanerozoic, and probably during the Late (i.e., post-900 Ma ago) Proterozoic (e.g. papers in Kroner, 1981 and Medaris et al., 1983). Application of plate tectonics tc the earlier Proterozoic record, however, is not as widely accepted, particularly amongst geologists working in the southern hemisphere (e.g. Kroner, 1983; Etheridge et al., 1987).

Hallmarks of the Wilson Cycle of ocean creation and destruction are diverse, including thick Atlantic-type miogeoclinal sequences, and the crucial ophiolites that

attest to former oceanic crust. Such features are absent (perhaps eroded) or strongly metamorphosed in many Proterozoic orogenic belts. Reconstructions of Proterozoic tectonic cycles thus depend heavily on interpretation of orogenic igneous rocks. Volcanic sequences are present in many areas (e.g. papers in Pharoah et al., 1987), but Proterozoic magmatic assemblages are dominated by intrusive rocks, mostly of granitoid composition. These differ radically from the sodic tonalites and trondhjemites that dominate Archean terranes (e.g. Taylor and McClennan, 1985), but their relationship to modern assemblages remains equivocal.

Several Proterozoic granitoid batholiths in the northern hemisphere have been described as "Andean" or "Cordilleran" (e.g. Hoffman, 1980; Lewry et al., 1981; Nystrom, 1982). However, geochemical studies of some have proved inconclusive, and illustrate many contrasts with modern arc magmas (e.g. Fumerton et al., 1984; Halden et al., 1987). The northern hemisphere Proterozoic also contains abundant, siliceous, potassic, evolved granitoid rocks ("rapakivi granites") and associated mafic intrusions of so-called "anorogenic" setting (e.g. Emslie, 1978; Anderson, 1983). Phanerozoic analogues of these rocks exist, particularly in Africa (e.g. Kinnaird and Bowden, 1987), but they are volumetrically insignificant compared to these Proterozoic examples.

Wyborn et al.(1987), Etheridge et al.(1987) and Wyborn (1988) have drawn attention to geochemical contrasts between Proterozoic and Phanerozoic granitoid assemblages in Australia, and propose that the former are products of vercical crustal accretion processes in an intracontinental environment, and unrelated to plate-margin processes. Page (1988) points out the episodic and continent-wide nature of Proterozoic magmatism in Australia, in contrast to the

tightly focussed, linear patterns of the Phanerozoic. These authors comment also on the siliceous, potassic and evolved geochemistry of Proterozoic granitoid rocks, and their partial affinity to anorogenic suites.

The Proterozoic was a critical period for growth of the continental crust. Orogenic belts of 1900 - 1700 Ma age are abundant cn a global scale, and (in the northern hemisphere at least), comprise vast tracts of "juvenile" crust separated from the mantle after 2000 Ma ago (Patchett and Arndt, 1986). It has been suggested that crustal growth rates at this time were several times greater than current *global* arc magma production (Reymer and Schubert, 1986). As crustal growth is synonymous with granitoid magmatism, Proterozoic batholiths are a vital key in unlocking the mechanism(s) of early crustal evolution. In particular, if such growth occurred primarily via arc magmatism (as is widely suggested), how can this be reconciled with the apparent geochemical contrasts between Protcrozoic and Phanerozoic granitoid batholiths ?

Resolution of these questions is hampered by poor knowledge of Early Proterozoic granitoid assemblages. Also, many modern or Phanerozoic granitoid assemblages that supposedly *define* tectonic environments are themselves poorly characterized, particularly in *representative* geochemical terms. This thesis attempts to address some of these problems via a large-scale geochemical and isotopic study of a major Proterozoic batholith in eastern Labrador, with reference to Phanerozoic magmatic assemblages, and the role of Proterozoic magmatism in crustal evolution.

Aims and Objectives

The focus of this study is referred to as the Trans-Labrador Granitoid Belt (TLGB). The TLGB is an

enormous zone of Lower and Middle Proterozoic plutonic rocks (and their metamorphic equivalents) that extends for ca. 600 km across Labrador (Figure 1.1). The study is localized in a well-exposed portion of the TLGB in the Makkovik Structural Province (Gower and Ryan, 1986) on the Labrador Coast. The principal objectives are listed below.

1. To document the geology, petrology and geochemistry of these plutonic rocks. Some have been described previously by localized studies, but integration of petrological and geochemical data over the entire area has never been attempted. Geochronological studies using Rb-Sr (this study) and U-Pb methods (Krogh et al., in prep.) play an important role in this work, particularly in defining discrete assemblages within the TLGB, as do results from a large-scale mapping and lithogeochemical program.

2. To examine the sources of TLGB magmas via Sr and Nd isotope geochemistry, and to provide models for their petrogenesis and evolution. This is the first Nd isotopic study of granitoid rocks in Labrador. In addition to this specific objective, Nd isotope studies are relevant to the origins of granitoid magmas and Proterozoic crustal evolution, particularly in terms of crustal growth models.

3. To attempt a quantitative comparative assessment with respect to Phanerozoic assemblages developed in various tectonic settings. In particular, can the TLGB magmatic assemblages be related directly to younger suites, or are they so distinct as to require a unique, non-uniformitarian tectonic model ? If modern analogues are identifiable, what type of environment(s) or process(es) do they suggest for generation of the TLGB and similar assemblages ?
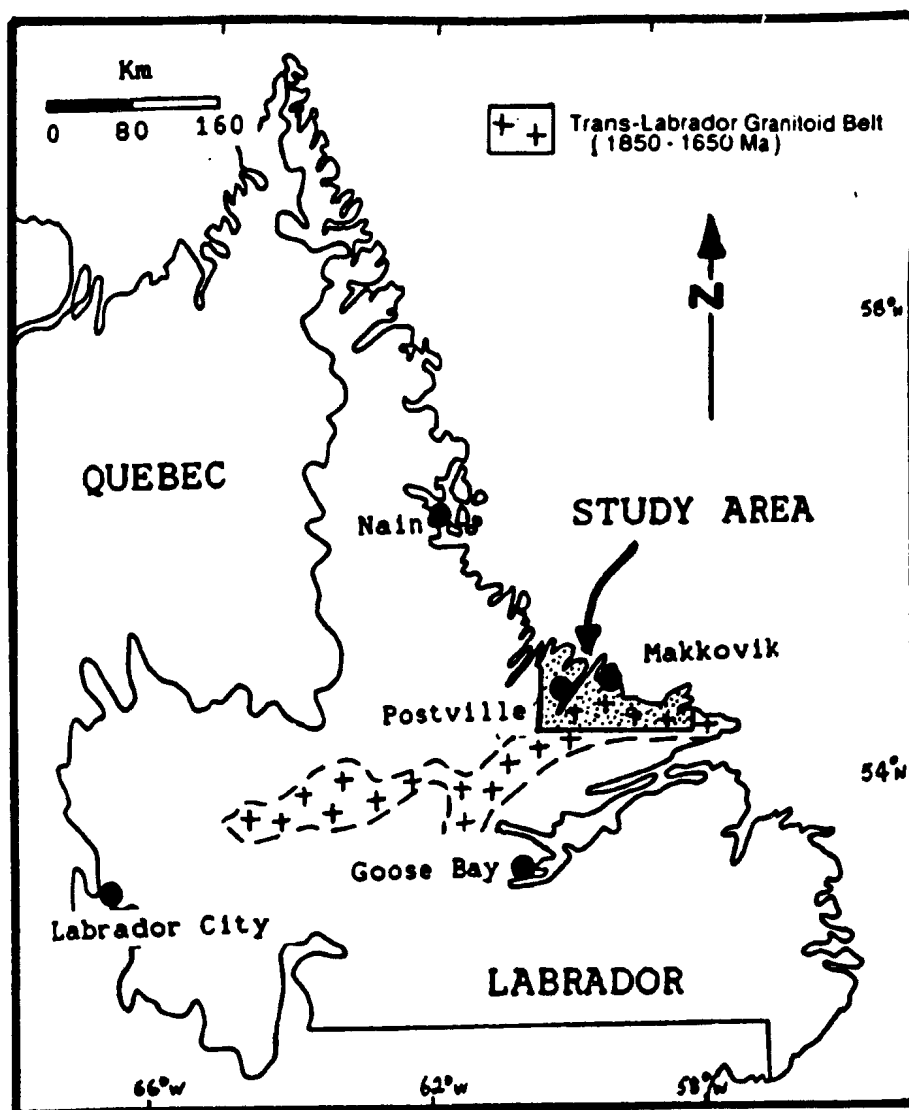
Figure 1.1. Location of the study area in Labrador, showing the approximate outline of the Trans-Labrador Granitoid Belt (TLGB).

4. To assess the role that the TLGB played in local crustal evolution and, on a wider scale, to examine implications for the role of Proterozoic magmatism in Earth history, and possible reasons for differences between these rocks and younger analogues. In particular, can such suites be accomodated in a plate-tectonic framework that is influenced by changing physical conditions (notably declining global heat production), or are non-uniformitarian tectonic models such as those of Kroner (1983) and Etheridge et al.(1987) required ?

Scale Considerations

This study is aimed at regional geologic problems and large-scale questions of Precambrian crustal evolution; the study area is huge, and several of the intrusive suites described herein are veritable research topics in their own right. It is impossible to deal fully with all aspects of this project within a Ph.D. dissertation. Many local details and contact relationships between units remain unresolved, and descriptions of units and their field relationships have been condensed. Some aspects of this study (e.g. specialized granites and mineral potential) are discussed elsewhere (Kerr, 1986; 1987; 1988). U-Pb geochronological data are being prepared for publication elsewhere as part of a joint project (Krogh et al., in prep.), and are only briefly summarized in Appendix D. Studies of restricted areas or time-slices in the TLGB (although undoubtedly of interest) would be uninformative in terms of the objectives above. It is important to consider the TLGB (and comparative assemblages) at the largest possible scale, and some local detail must unavoidably be sacrificed to acheive this. It is hoped that this study will establish a framework for future work.

1.2 GENERAL INFORMATION

Location, Topography and Access

The study area is located approximately 150 km
northeast of Goose Bay (Figure 1.1), and includes the
northern half of NTS 1:250,000 sheet 13J, the eastern edge
of sheet 13K, and parts of sheet 13O. A rugged,
well-exposed, mountainous terrain (maximum elevation 875 m
above sea level) dominates eastern and northern portions of
the area. The coastline is incised by several deep fiords
(e.g. Makkovik Bay) and is protected from the vagaries of
the Labrador Sea by numerous offshore islands. The southern
and western parts of the study area consist of a variably
wooded, boulder-strewn plateau that is largely obscured by
glacial drift, with the exception of hilltops and
watercourses. "Summer" conditions prevail from late June to
late August, and are an extreme mixture of cold, damp
weather and hot, humid, fly-infested periods. In Labrador,
geologists are widely regarded as the only individuals
foolish enough to attempt inland travel during the summer.

The communities of Makkovik and Postville (Figure 1.1)
are served by Marine Atlantic coastal boat service from
June to November, and by year-round scheduled (*sensu
lato*) flights operated by Labrador Airways. The project
from which this thesis evolved was operated from Makkovik,
and from a dormant mineral exploration camp at Melody Lake,
some 30 km south-west of Postville.

The coastline provides access to some of the northern
and eastern parts of the area, but easy access to the
hinterland is possible only by air. The size of the area
involved in this project is such that its coverage would
have been impossible without extensive helicopter support.

Previous Work From 1814 to 1985

Geological research on the coast of Labrador commenced with the work of Steinhauer (1814). This, and subsequent studies (e.g. Leiber, 1860; Packard, 1891; Daly, 1902), consisted largely of descriptions of coastal outcrops. The first mapping in coastal areas was conducted by the Newfoundland Geological Survey and Geological Survey of Canada (Kranck, 1939;1953; Christie et al., 1953; Douglas, 1953). 1:250,000 geological mapping, including coverage of inland areas, was completed by the Geological Survey of Canada in the 1970s (Stevenson, 1970; Taylor, 1975).

In 1954 Murray Piloski of British Newfoundland Exploration Company Ltd (BRINCO) discovered pitchblende near Makkovik. This led to a 25-year period of uranium, molybdenum and base-metal exploration by BRINCO and several joint venture partners (see Gower et al.,1982 and Ryan, 1984 for details). Most of the exploration and research work from 1955 to 1978 was related to the search for economic mineralization in uranium-bearing supracrustal sequences. Many of these studies remain confidential, but some general results were published by BRINCO geologists (e.g Beavan, 1958; Gandhi et al., 1969; Gandhi, 1978). Uranium deposits at Kitts and Michelin were evaluated for commercial development in the late 1970s. Several more general studies with economic implications were carried out via university theses supported partly by BRINCO. These included documentation of mineralization (e.g. Gill, 1966; Barua, 1969), and also regional geological and structural syntheses (Clark, 1973,1979; Marten, 1977) in the Makkovik and Kaipokok Bay areas. The study of Marten (1977) was

particularly influential in unravelling the structural evolution of the area. A third group of thesis studies emphasized petrological and geochemical studies of uranium-bearing volcanic rocks (White, 1976; Evans, 1980).

The Newfoundland Department of Mines (NDM) started work in the area in 1976 and completed regional 1:100,000 mapping in 1980 (Bailey, 1979; Bailey et al., 1979; Ryan and Harris, 1978; Doherty, 1980; Gower, 1981). Compilation and synthesis of this information was presented by Gower et al.(1982) for the eastern half and by Bailey (1979) and Ryan (1984) for the western half of the area. These programs focused mostly on supracrustal sequences, but the areal importance of post-tectonic granitoid rocks was recognized, as was their polyphase and compositionally variable nature.

Central Mineral Belt Granitoid Project

Re-examination and sampling of a number of mineral occurrences in the study area during 1984 (Wardle, 1984; Wardle and Wilton, 1984) awakened interest in both the gold potential of the area and the possible importance of post-tectonic granitoids as hosts or progenitors to mineralization. The "Central Mineral Belt Granitoid Project" (CMBGP) was initiated to define and delimit plutonic associations and assess their potential for economic mineralization. This commenced with geochemical sampling and mapping in 1985, leading to revision of existing unit designat'.·ns and definition of new regional granitoid units (Kerr, 1986). Analysis of geochemical data led to the identification and delineation of several granitoid associations considered to have some of the

characteristics of specialized granites (Kerr, 1987). The
1986 field season included follow-up mapping and sampling
in these areas, and extension of regional coverage eastward
into the Benedict Mountains. The petrology and geochemistry
of possible specialized granitoid rocks in the area was
discussed in more detail by Kerr (1988a).

The CMBGP was co-ordinated throughout its duration
with related metallogenic studies by Derek Wilton and
co-workers. These include thesis studies of granite-
related mineral prospects (e.g. MacDougall, 1988;
MacKenzie, 1988), and general assessment of the role of
granitoid rocks in metallogenesis throughout the Central
Mineral Belt (Wilton et al., 1986, 1987).

Relevant Work Outside The Study Area

Systematic mapping conducted by the NDM has led to
substantial re-interpretation of geotectonic divisions
within Labrador. Geological and geochronological
investigations in central Labrador (Wardle et al.,
1982,1986; Nunn et al.,1985; Thomas et al.,1986) defined
the geologic entity termed the Trans-Labrador Batholith,
and also identified a ca. 1650 Ma old cryptic orogenic belt
(Labrador Orogen) within the area occupied by the ca.1100
Ma Grenville Province. Geologic mapping in areas adjacent
to the study area (Ryan and Kay, 1982; Gower et al.,1980;
Gower, 1986; Gower and Ryan, 1986, Owen et al.,1986) is
also relevant to this project, and is discussed in the
appropriate chapters.

1.3 TERMINOLOGY and NOMENCLATURE

Classification and Nomenclature of Plutonic Rocks

The nomenclature of plutonic rocks is based on modal proportions of quartz, alkali feldspar and plagioclase feldspar. The IUGS classification (Streckeisen, 1976; Figure 1.2a) is employed in this thesis, with substitution of the term "monzogranite" for the "3b" granite field of the IUGS scheme; the term "granite" is restricted to the "3a" granite field, although it is used *sensu lato* in some unit names. Rock names assigned in this thesis are visual estimates from cut slabs stained for K-feldspar. No point-counting of sections or slabs was attempted, as most TLGB rocks are coarse grained and/or porphyritic.

In comparative studies, an unbiased method of defining rock types is required; classification via normative mineralogy is ·the preferred method. Streckeisen and LeMaitre (1979) provide an empirical equivalent to the IUGS scheme using the parameters $Q' = [Q / (Q + Ab + An + Or)]$ and ANOR [An / (An + Or)] (Figure 1.2b). The recommended normative calculation scheme is the mesonorm[*]of Barth (1955), which incorporates hydrous minerals such as hornblende and biotite. This system is used widely in this thesis to provide a method of comparing and subdividing suites or assemblages. It is not used to assign unit names, but there is general agreement between names based on modal estimates and those calculated from norms.

The term "granitoi 1" lacks precise definition, but is generally used for all ׀haneritic plutonic rocks from diorite to alkali-feldspar granite (e.g. Strong, 1981). It includes most of the fields in Figure 1.2, with the exception of gabbro.

[*] see note in caption for figure 1.2

A

Quartz

Alkali Feldspar

Plagioclase

GRNT (3a Granite) — MZGT (3b Granite) — GRDR

AFGT — TNLT

AFQS — QSZT — QZMZ — QZMD — QZDR

AFST — SENT — MNZN — MZDR — DORT

B

$Q' = [Q/(Q + Ab + An + Or)] \times 100$

$ANOR = [An/(An + Or)] \times 100$

AFGT - Alkali Fsp Granite
AFQS - Alkali Fsp Quartz Syenite
AFST - Alkali Fsp Syenite
GRNT - Granite (s.s.)
QSZT - Quartz Syenite
SENT - Syenite
MZGT - Monzogranite
QZMZ - Quartz Monzonite
MNZN - Monzonite
GRDR - Granodiorite
QZMD - Quartz Monzodiorite
MZDR - Monzodiorite
TNLT - Tonalite
QZDR - Quartz Diorite
DORT - Diorite
QZGB - Quartz Gabbro
GBBR - Gabbro

(all values are mesonorms)

Figure 1.2. Classification and nomenclature of common plutonic rocks. (a) Modal classification of Streckeisen (1976). (b) Normative classification of Streckeisen and Lemaitre (1979).

NOTE: In practice, CIPW and Barth mesonorms yield almost identical results in the Streckeisen and LeMaitre system, as shown also by Bowden et al.(1984) for a range of rock types. For the sake of consistency with the original paper, I have employed the mesonorm.

Descriptive Geochemical Terminology

Simple, descriptive geochemical terms outlined by Shand (1927) are used extensively in this thesis. In contrast to many other geochemical terms (see below), these have direct implications for varietal mineralogy.

The alumina index or A/C+N+K ratio [molecular $Al_2O_3/(CaO+Na_2O+K_2O)$] divides rocks into metaluminous (A/C+N+K < 1) and peraluminous (A/C+N+K > 1) categories. Alumina oversaturation in the latter group permits formation of aluminous phases such as muscovite, garnet and cordierite.

The agpaitic index or K+N/A ratio [molecular $(K_2O+ Na_2O)/Al_2O_3$] provides distinc : n into peralkaline (K+N/A > 1) and subalkaline (K+N/A < 1) categories. There is a common misconception (e.g. Bowden et al., 1984) that peralkalinity is also implied by A/C+N+K < 1; this is not so, except in rocks with negligable CaO. Peralkaline rocks are oversaturated in (Na_2O+K_2O), and may contain alkali-bearing mafic silicates, e.g. reibeckite and aegirine. If this property is combined with a low silica content, such rocks may contain feldspathoids such as nepheline or leucite. The term peralkaline is distinct from "alkaline", as commonly applied to mafic rocks. The latter has no precise definition, and refers only to relatively high (Na_2O+K_2O) at a given CaO or SiO_2 content (see below).

Peacock (1931) introduced the alkali-lime index (ALI; SiO_2 content at which K_2O+Na_2C is equal to CaO), and also the terms alkaline (ALI < 51% SiO_2), alkali-calcic (51% < ALI < 56% SiO_2), calc-alkaline (56% < ALI < 61% SiO_2) and calcic (ALI > 61% SiO_2). These are arbitrary

divisions, but modern petrology has endowed the terms with genetic meanings beyond their original definition. The ALI cannot be measured directly in granites with high (K_2O+Na_2O) / CaO ratios, but may be estimated by linear regression.

Two other descriptive terms employed in this thesis are the soda-potash ratio [N/N+K ; $Na_2O/(Na_2O+K_2O)$] and the iron-magnesium ratio [F/F+M ; FeOt/(FeOt+MgO)]. The latter uses total iron expressed as FeO (FeOt). The term sodic is used where N/N+K > 0.5 and potassic where N/N+K < 0.5. No descriptive labels are attached to F/F+M, which is a measure of relative iron enrichment.

Geochemical classifications developed by French researchers (e.g. La Roche, 1980; Debon and Lefort, 1982) are employed locally in this thesis. The "characteristic minerals" method of Debon and LeFort (1982) expresses oxides as cation proportions (x1000), and defines the following parameters.

Q = Si/3 - (K + Na + 2Ca/3) [measure of silica saturation]
P = K - (Na + K)
A = Al - (K + Na + 2Ca) [measure of alumina saturation]
B = Fe + Mg + Ti
F = 555 - (Q + B)

These methods are hampered by the the need for sequential calculations, and by complex descriptive terminology. Conventional normative parameters or molecular ratios provide the same information in a more familiar mineralogical framework. Nevertheless, the Q-B-F ternary projection of Debon and LeFort (1982) was found to have some utility in this study.

Descriptive terminology used to subdivide trace
elements into groups (Table 1.1) is adapted from Saunders
et al. (1979). The new term "Octahedrally Co-ordinated
Cation" (OCC) elements refers to the ability of divalent
cations to substitute for Mg^{2+} and Fe^{2+} in common mafic
silicate minerals. These correspond to the "compatible"
trace elements of conventional terminology. The distinction
is made because elements such as Ba and Sr may be
compatible in granitoid magmas, yet are geochemically
distinct from V, Cr, Cu and Ni.

Environments of Granitoid Magmatism

The theory of plate tectonics provides a framework for
classification of present-day and recent (i.e. Mesozoic -
Cenozoic) environments of granitoid magmatism. Large-scale
silicic magmatism is essentially a continental phenomenom,
although minor amounts of felsic volcanic rocks are
associated with oceanic settings, particularly island arcs.
Tectonic settings of continental granitoid magmatism are
grouped loosely into three environments (e.g. Pitcher,
1983; Pearce et al., 1984).

Volcanic Arc Magmatism : Arcuate orogenic belts
associated with subduction beneath continental margins
(e.g. the Andean-Cordilleran belt) are characterized by
long-lived zones of volcanism and plutonism that parallel
the trench axis. The least differentiated granitoids have
affinities to plutonic rocks in intra-oceanic island arcs,
but most continental arcs contain compositionally ex, anded
suites dominated by metaluminous to peraluminous, sodic

Table 1.1. Descriptive terminology used for trace element
associations. Classification adapted from Saunders et al.(1979), with
modifications to suit granitoid rocks rather than basalts.

1. OCTAHEDRALLY CO-ORDINATED CATION (OCC) ELEMENTS

*Elements with divalent cations that substitute readily in
the octahedral (co-ordination = 6) sites in rock-forming Mg
and Fe silicates. They accumulate in crystallizing phases
and therefore show COMPATIBLE behaviour.*

Sc V Cr Co Ni Cu (also MnO in most granites)

2. LOW FIELD STRENGTH (LFS) ELEMENTS

*Elements with a charge/radius ratio of < 0.2. In general,
they are excluded from common silicates and accumulate in
residual liquids, showing INCOMPATIBLE behaviour. This is,
however, not so for Ba and Sr, which can enter feldspars.
Rb may enter biotite or muscovite.*

Rb Cs U Th Pb Sr Ba

3. HIGH FIELD STRENGTH (HFS) ELEMENTS

*Elements with a charge/radius ratio of > 0.2. These
commonly show INCOMPATIBLE behaviour, but are very strongly
influenced by residual phases, particularily zircon,
allanite, monazite, sphene and apatite. They are also
widely regarded as "immobile".*

Zr Hf Nb Ta Sn W Mo (also TiO_2 and P_2O_5
in granites)

4. RARE EARTH ELEMENTS (REE)

*Trivalent (except Eu) elements whose behaviour is
sensitive both to accessory and major phase assemblages in
residual material. Y is included, although not technically
a member of the rare earth (lanthanide) series.*

Y La Ce Pr Nd Sm Eu Gd Tb
Dy Ho Er Tm Yb Lu

5. "INDETERMI.'ATE" TRACE ELEMENTS

*Elements whose behaviour may vary widely depending on
major phase assemblages in residual material and upon other
chemical and physical factors.*

Li Be Ga Zn As Sb F

diorite, tonalite and granodiorite. These suites are commonly calcic to calc-alkaline. "Mature" oceanic island arcs include intermediate plutonic rocks that overlap extensively with continental arc suites.

Collision Zone Magmatism : Zones where subduction of oceanic lithosphere has ceased, but continental blocks continue to converge (e.g. the Alpine-Himalayan belt), are also characterized by large-scale granitoid magmatism. Geophysical data commonly indicate that such zones are underlain by anomalously thick continental crust, implying tectonic thickening via thrusting. Collisional zones contain a wide variety of igneous rocks, but most that accompany or follow collision are compositionally restricted monzogranite to granite. Peraluminous two-mica leucogranites are a characteristic component of many such zones. In detail, collisional orogens are tectonic collages of pre-, syn- and post-collisional magmatic environments (Debon et al.,1986; 1987a; Harris et al., 1984), and thus commonly include rocks of volcanic-arc type amongst their earliest components. Post-collisional suites associated with tensional or transcurrent tectonics may also resemble granites of the within-plate group (see below).

Within-Plate Magmatism : Silicic magmatism is also associated with uplift and tensional tectonics in stable cratonic areas. Examples include the modern East African Rift Sytem, and Mesozoic granites of Nigeria and Niger (Kinnaird and Bowden, 1987). The latter were probably associated with the break-up of Gondwanaland. Continental within-plate magmatic zones contain diverse magmatic

assemblages, commonly of bimodal, alkaline-peralkaline or silica-undersaturated character. Peraluminous compositions are rare. In terms of volume, within-plate zones are insignificant compared to the huge batholiths generated in volcanic arc and collision zone environments. The term anorogenic is also commonly used for granites of this association.

Continuity of Tectonic Environments : The above tectonic environments do not occur in temporal or spatial isolation, but are transient situations in orogenic evolution. For example, collisional events are an unavoidable consequence of subduction. Current models for the evolution of complex belts such as the North American Cordillera (e.g. Coney et al.,1980) suggest accretion of island arcs and continental fragments against active margins. Such models imply that collisions occur repeatedly during orogenic evolution. Similarly, rifting and uplift associated with within-plate magmatism may occur in post-collisional situations (Harris et al., 1984), or in back-arc settings, distal from the locus of subduction (Brown et al., 1984). It is also important to realize that unique rock types characteristic of specific environments do not exist; there is instead a continuum of compositions.

Classifications Based On Source Materials

The restriction of granitoid magmatism to continental areas has led some (e.g. Chappell and White, 1974; White and Chappell, 1977) to suggest that most granitoid rocks are derived wholly from continental crust. Others contend

that they are mostly of mantle origin (e.g. Brown, 1981) or represent mixtures of crust and mantle (e.g. Didier et al., 1982). This has given rise to a veritable jungle of terminology.

I, S, A and M-type Granites : A viewpoint prevalent in Australia contends that granitoid magmas "image" their sources in a simple and direct manner (e.g. Chappell and White, 1974; Chappell et al., 1988; Chappell and Stephens, 1988). Chappell and White (1974) divided granites into I-type (igneous source) and S-type (sedimentary source) categories. These terms were later redefined to denote "infracrustal" and "supracrustal" respectively (White and Chappell, 1983). S-type granites are peraluminous, and are defined by a parameter equivalent to the A/C+N+K ratio. In contrast, I-type granites are metaluminous, calcic and compositionally varied suites. The characteristics of S-type granites are supposedly inherited from sources that have passed through the surface environment.

Loiselle and Wones (1979) and Collins et al. (1982) added "A-type" (anorogenic or anhydrous) granites to the list. These are evolved, metaluminous to peralkaline rocks, considered to be anatectic derivatives of dehydrated lower crustal rocks. Pitcher (1983) introduced "M-type" (mantle) granites for calcic, plagioclase-rich intrusive rocks of oceanic areas considered to have mantle or mafic sources.

Antipodean Viewpoints and the Restite Model : Many petrologists (particularly in Australia) contend that compositional variation in granites results from "unmixing" of residual source material and anatectic melt (e.g. White

and Chappell, 1976). In extreme cases, the process of <u>total</u>
mobilization, or "remagmatization" (Chappell and Stephens,
1988) has been invoked to explain calcic or tonalitic
I-type granites that are otherwise difficult to accomodate
in this model. The restite model is so entrenched that
other types of information, e.g. Nd and Sr isotopic data
indicative of crust-mantle mixing, have been questioned on
the basis of incompatibility with predictions of the model
(e.g. McCulloch and Chappell, 1982). Most workers accept
that "source" is indeed an important factor in magmatism,
but dogmatic application of the restite hypothesis has been
widely questioned (e.g. Strong, 1980; Gray, 1984; Hildreth,
1987; Wall et al., 1987).

The Pseudo-Descriptive Viewpoint : The restite model
has not been widely accepted in Europe or North America,
but its associated terminology is epidemic. I, S, A and
M-type granitoids are, however, viewed as broad
petrochemical groups that owe their differences to both in
source characteristics <u>and</u> processing environment. For
example, I-type granites are subdivided into Cordilleran
and Caledonian subcategories developed at different stages
in orogenesis (Pitcher, 1983). M-type and I-type
(Cordilleran) granites are viewed as partly gradational; an
implicit recognition that the latter are not wholly of
crustal origin. Although this *sensu lato* usage of the
source-image terminology is probably more realistic than
the antipodean view, there is a tendency to view these
granite types as simplistic indicators of geotectonic
environments (e.g. Nystrom, 1982).

Classifications Based On Tectonic Environment

Empirical classifications based on the trace element geochemistry of granitoid rocks from "known" tectonic settings (see above), are currently popular.

Pearce et al. (1984) coined the terms Ocean-ridge (ORG), Volcanic-Arc (VAG), Collisional (COLG) and Within-Plate (WPG) granites, and proposed distinction using trace element patterns. In general terms, these correspond to M-type, I-type, S-type and A-type granites as defined by Pitcher (1983), but there is significant overlap, particularly in "collisional" granites, which coincide partly with VAG and WPG fields. Harris et al.(1984) analyzed collisional granites in a similar fashion, and recognized four discrete types, including rocks that correspond to the VAG and WPG groups of Pearce et al. (1984). A similar study of arc-related granitoids by Brown et al. (1984) outlined a concept of "arc maturity" (i.e. age or distance from the locus of subduction). Mature (old or distal) arcs include granites similar to the COLG and WPG groups defined by Pearce et al.,(1984) and Harris et al. (1984). All three studies employ essentially the same trace elements (Rb, Zr, Y, Nb, Ta) as discriminants !

It is clear that there are no simple correlations between tectonic setting and trace element geochemistry. However, this has not prevented almost universal use of such discrimination diagrams in studies of ancient granitoid rocks. In a subsequent chapter of this thesis, it is shown that examination of compositional spectra and evolutionary trends may, in combination with these methods, provide better definition of contrasting granitoid assemblages.

Investigative Methods

The general geology of the study area is established
by previous studies (Gower, 1981; Gower et al.,1982; Ryan,
1984). This project is thus a thematic mapping and sampling
project, aimed largely at the plutonic rocks of the TLGB.
In view of the large area (Figure 1.1), this work was
accomplished mostly by a large-scale, grid-based mapping
and geochemical sampling program carried out with
helicopter support. Ground-based work was carried out only
in well-exposed or critical parts of the area, and along
the superb coastline exposures.

Sample Populations

In total, over 1500 samples were collected and
analyzed under the auspices of the the Central Mineral Belt
Granitoid project. These can be divided into three groups.
Regional samples were collected on a regular grid at
intervals of ca. 2 km using a sample site preselected on a
random basis. These provide an unbiased view of the
compositional anatomy of intrusive suites and units, and
are representative of the areal abundance of rock types.
Follow-up samples were collected on a regular grid at
intervals of ca. 1 km using random site selection methods.
They were collected from selected suites defined by
regional sampling, to provide assessment of mineralized or
potentially specialized granitoid rocks. Geological samples
were collected routinely during mapping. They represent
typical examples of units, or mineralogical-textural
variants thereof.

Regional and follow-up sampling methodology is based on geochemical exploration techniques (e.g. Garrett, 1983), and sampling projects in the Ackley Granite of southeastern Newfoundland (Dickson, 1983, Tuach et al., 1987). The regional population is representative of the TLGB as a whole, with no bias towards specific compositions or areas. The follow-up population, on the other hand, is strongly biased towards evolved, high-SiO_2 granitic compositions. It is therefore excluded from discussions relating to large-scale, regional patterns, but is retained for descriptions of specific units or suites. The geological sample population is the smallest and, although compositionally representative, is slightly biased towards coastal areas. Assessment of frequency spectra and univariate statistics indicates, however, that the characteristics of the regional population are unaffected by its inclusion. The two populations have therefore been combined for most interpretative discussions.

Geochronology samples, consisting of 20-40 Kg of fresh material, were acquired for U-Pb geochronology at selected localities (Krogh et al., in prep.), and were also used for rare earth element (REE), Sm-Nd and Rb-Sr isotopic analysis. Additional REE, Sm-Nd and Rb-Sr analyses were performed using samples selected from regional, follow-up and geological populations.

Overview Of Geochemical Analysis Program

Full details of anlaytical techniques, including estimates of precision and analyses of international standards, are presented in Appendix A. A brief overview is presented below as a convenience to the reader.

Major Elements : Major elements were analyzed by atomic absorption spectrometry (AAS) at the Newfoundland Department of Mines (NDM) Laboratory in St,John's. Based on 73 random duplicate analyses, the median (50th percentile) analytical precision is ± 5.0 % or better for all oxides except Fe_2O_3 (6.5%).

Trace Elements by AAS : Li, V, Cr, Ni, Cu, Zn, Rb, Sr, Ba and Pb were determined by AAS at the NDM laboratory. Median precision for all is ± 5.0 % or better, except for Li (8.2%).

Trace Elements by ICP-ES : Ga, Y, Zr, Nb, La, Ce and Th were determined by inductively-coupled plasma emission spectroscopy at the NDM laboratory. Median precision for all is ± 5.0 % or better, except for Th (13.3 %). The latter is affected by determinations at or near detection limit in mafic rocks; precision for granites is considerably better.

Trace Elements by INAA : Sc, Cs, Sm, Yb, Hf and U were determined by instrumental neutron-activation analysis by Becquerel Ltd. and Nuclear Activation Services Ltd.(U) laboratories. Median precision is ± 6.0 % or better, except for Sc (9.5%) and Hf (12.2%).

Other Trace Element Methods : Fluorine (ion-selective electrode method; NDM) has median precision of ± 9.4%. Sn (XRF, Bondar-Clegg) has poor median precision of ± 66 % ; this reflects near-detection limit levels of Sn in most samples; the method is capable of resolving anomalous data only.

Rare-Earth Element Analyses by ICP-MS : The rare
earth element (REE) analyses presented here were determined
by inductively-coupled plasma mass spectrometry (ICP-MS)
at Memorial University. Precision for all elements by this
method is estimated at ± 5.0 % or better (H.Longerich
and S.Jackson, pers. comm., 1988).

CHAPTER TWO
GEOLOGICAL FRAMEWORK

Chapter Abstract

In southern and eastern Labrador, the Makkovik Province and the Grenville Province are part of a long-lived Proterozoic mobile zone that can be traced from Scandinavia to Mexico. Much of the Grenville Province in Labrador is a reworked ca. 1650 Ma old mobile belt termed the Labrador Orogen. A major, arcuate belt of granitoid rocks, termed the Trans-Labrador Granitoid Belt (TLGB), forms the northern edge of the Labrador Orogen. In the Makkovik Province, the TLGB is a composite belt including Makkovikian (ca. 1800 Ma) and Labradorian (ca. 1650 Ma) plutonic assemblages.

The oldest rocks in the study area are Archean gneisses. These form the basement to metasedimentary - mafic volcanic supracrustal sequences (Moran Lake and Lower Aillik Groups) that are at least 1860 Ma old. These rocks are overlain by a thick felsic volcanic sequence (Upper Aillik Group), deposited ca. 1860 - 1800 Ma ago. All of these rocks were affected by Makkovikian deformation ca. 1800 Ma ago.

Early Proterozoic plutonic rocks form three main associations. "Syn-tectonic" Makkovikian plutonic rocks (emplaced ca. 1840-1800 Ma ago) underwent the final episode(s) of Makkovikian deformation. "Post-tectonic" Makkovikian plutonic rocks (1800-1760 Ma) overlap in age with the syn-tectonic association, suggesting that both groups form a single magmatic pulse that transcends the Makkovikian orogeny. The plutonic rocks are dominated by quartz monzonite to granite, and are probably temporally equivalent to parts of the Upper Aillik Group. Labradorian plutonic rocks (1670-1600 Ma) are entirely post-tectonic, and consist of layered gabbro-monzonite-syenite intrusions, and quartz monzonite to granite plutons. A Labradorian volcanic sequence (Bruce River Group) occurs west of the study area. There is no evidence of Labradorian deformation in the Makkovik Province.

The southern part of the area was subsequently affected by Grenvillian deformation, which imposed east-trending fabrics on most of the above. A number of major east-trending Grenvillian faults divide the remainder of the area into structural blocks that expose differing crustal levels.

2.1 REGIONAL GEOLOGY

General Geology Of Labrador

The geology of Labrador is illustrated and discussed by Greene (1974) and Nunn et al.(in prep.). Labrador is divided into five Precambrian structural provinces (Figure 2.1), based on trends and "stabilization events" defined by Rb-Sr and K-Ar age data (after Stockwell, 1972). The Nain and Superior Provinces are of Archean age (stabilized ca. 2800-2500 Ma ago), and are separated by the Proterozoic Churchill Province (stabilized ca. 1800 Ma ago). The Nain Province is part of the North Atlantic Archean Craton (Bridgwater et al., 1973), and was originally contiguous with west Greenland (Figure 2.1). The Nain Province is bounded to the southeast by the Proterozoic Makkovik Province (Gower and Ryan, 1986), which was mostly stabilized ca. 1800 Ma ago, but includes some ca. 1650 Ma old intrusive rocks.

The southern part of Labrador forms part of the Grenville Province, which was stabilized ca. 1100 Ma ago. Geochronological studies completed since 1980 (e.g. Wardle et al., 1986; Thomas et al., 1986) have shown that many gneisses in the Labrador portion of the Grenville Province were formed and/or metamorphosed ca. 1650 Ma ago. Mapping has shown that it is composed of a number of thrust-bounded terranes that were assembled into their current positions
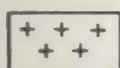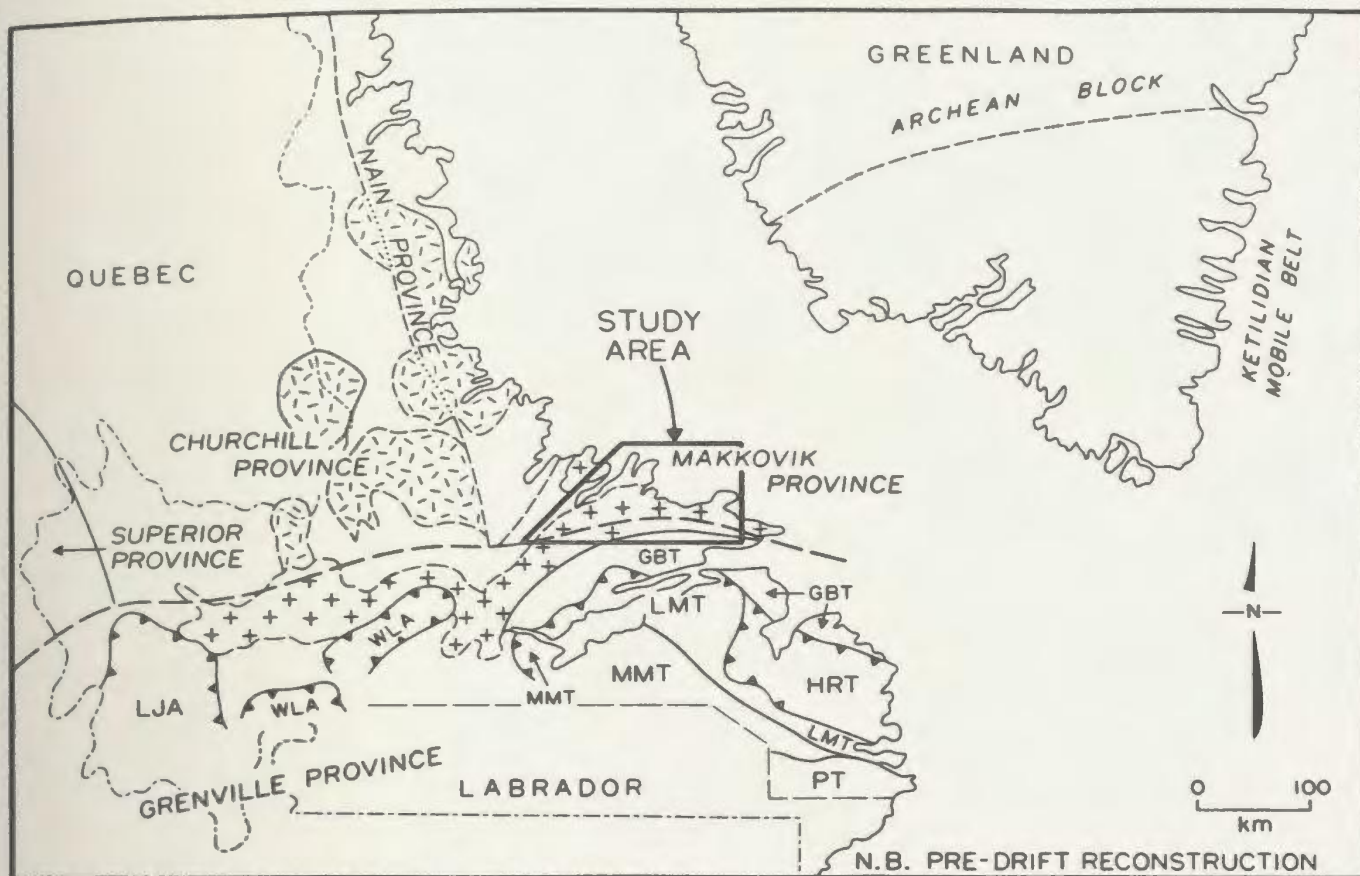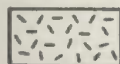
Figure 2.1. Summary map showing major structural provinces in Labrador and adjacent parts of Greenland, location of the Trans-Labrador Granitoid Belt (TLGB), and locations and names of Labradorian high-grade terranes contained within the Grenville Province. Compiled from Gower and Ryan (1986), Wardle et al. (1986) and Gower et al. (1987, 1988). For descriptions of Labradorian Terranes, see these references. Dashed line in southern Labrador indicates current limit of mapping.

during or prior to the Grenvillian Orogeny. These terranes represent a structurally reworked belt of ca. 1650 Ma old crust termed the Labrador Orogen (Thomas et al., 1986), and are termed the Labradorian high-grade terranes. The interface between the high-grade terranes and older structural provinces to the north is marked by the Trans-Labrador Granitoid Belt (TLGB), discussed in detail below.

In addition to the major structural provinces discussed above, the Nain and Churchill Provinces are intruded by anorogenic gabbro-anorthosite-granite plutons of ca. 1500-1300 Ma age (e.g. Emslie, 1978).

Labrador as Part of a Proterozoic Supercontinent

Paleomagnetic evidence (e.g. Piper, 1983) suggests that the shield areas of the northern hemisphere formed a single mass throughout much of the Proterozoic. Lower and Middle Proterozoic mobile belts occur all along the southern margin of this supercontinent (Figure 2.2), but are largely overprinted by the younger Grenville Province. The Makkovik Province is continuous with the Ketilidian mobile belt of Greenland (Allaart, 1976; Gower and Ryan, 1986), and (ultimately) with the Svecofennian Province of Scandinavia (Gower and Owen, 1984). Equivalents of the Labradorian high grade terranes are present in the Sveconorwegian belt (Gower and Owen, 1984). As in Labrador, the interface between these ca. 1650 Ma old terranes and older parts of Scandinavia is marked by a major belt of granitoid plutonic rocks, termed the Småland-Varmland or Trans-Scandinavian Granitoid Belt (Lindh, 1987). Gower and Owen (1984) suggested that this is equivalent to the TLGB.
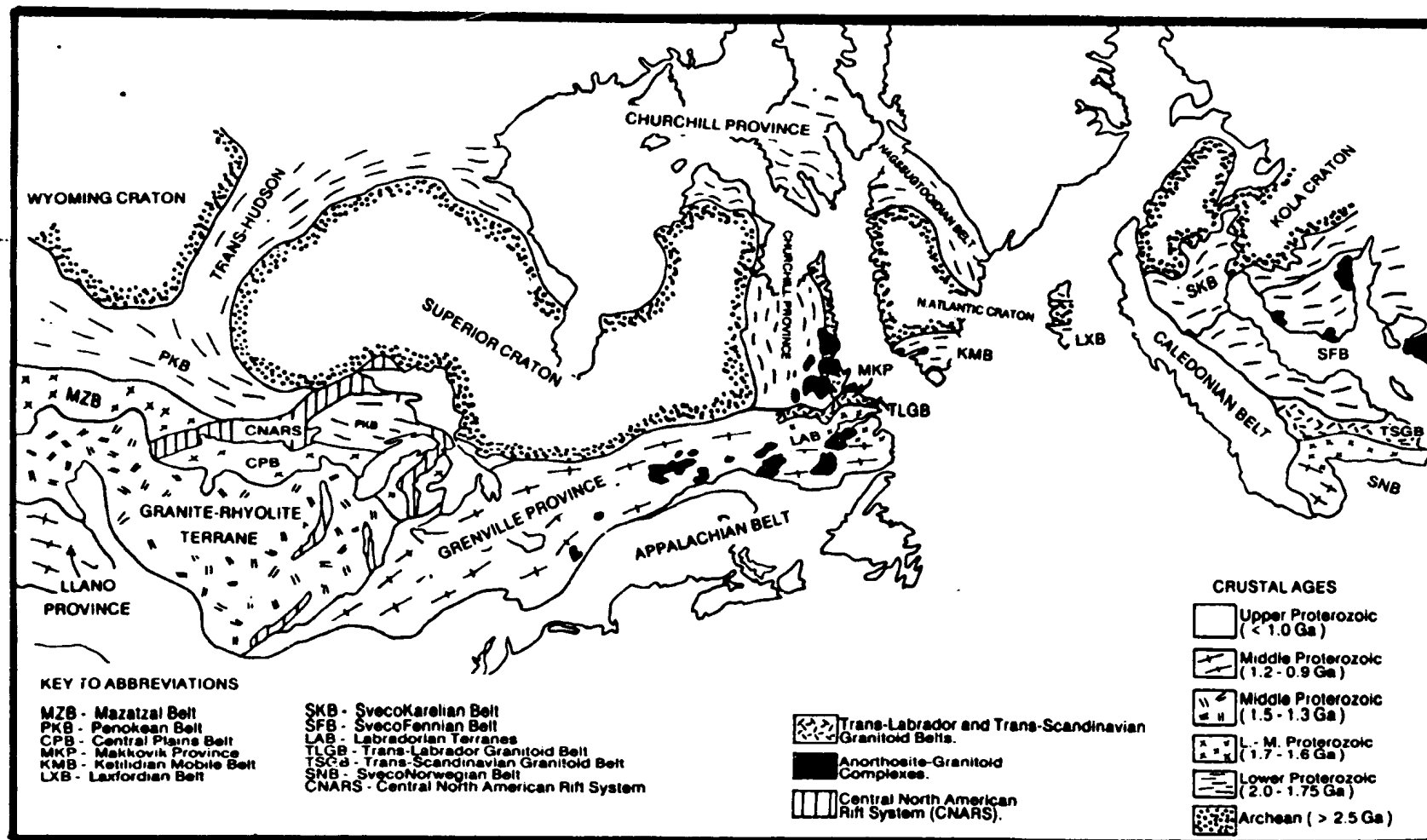
Figure 2.2. Lower and Middle Proterozoic mobile belts along the "southern" margin of a Precambrian supercontinent (Piper, 1983). Correlations are based on Gower and Owen, 1984, Thomas et al., 1985, and Gower (unpublished data). Map adapted from an original by C.F.Gower.

In the central and western United States, a number of Lower and Middle Proterozoic terranes have been recognized in the subsurface and as basement uplifts (Condie, 1981, 1982; Van Schmus and Bickford, 1981; Sims et al., 1987). These include probable equivalents of the Makkovik Province and Labrador Orogen (Thomas et al., 1985).

Post-1600 Ma rocks in the midcontinent region can also be correlated broadly with Labrador geology. The 1500 to 1300 Ma granite - rhyolite terrane (Sims et al., 1987) is probably equivalent to the anorogenic magmatism in Canada (Emslie, 1978; Anderson, 1983). The Grenville Province is largely coincident with the younger Appalachian Orogen, but emerges to form the ca. 1100 Ma old Llano Province of Texas and northeastern Mexico (Condie, 1981).

Trans-Labrador Granitoid Belt

Definition : The Trans-Labrador Granitoid Belt (TLGB) corresponds generally to the Trans-Labrador Batholith of Wardle et al.(1982). It was previously considered to be mostly ca. 1650 Ma in age (Gower and Owen, 1984; Wardle et al., 1986; Kerr, 1986, 1987) and, in general terms, to be part of the Labrador Orogen. Rb-Sr and U-Pb geochronology (this study; Krogh et al.,in prep.) demonstrate, however, that undeformed plutonic rocks in the study area include suites of both ca. 1650 Ma and ca. 1800 Ma age. The latter are similar in age to _foliated_ granitoid rocks that had previously been recognized as a distinct, older, assemblage (Gower and Owen, 1984; Gower and Ryan, 1986).

Trans-Labrador Granitoid Belt, as defined here, includes both foliated and undeformed Early Proterozoic plutonic rocks in the study area. The older and younger components of the belt are termed Makkovikian and

Labradorian assemblages respectively, with reference to the orogenic events with which they appear to be broadly associated (see below). The term "granitoid belt" is preferred over "batholith", as it more clearly indicates the probable composite nature of the belt.

In central and western Labrador, the TLGB is deformed and metamorphosed, and there is (as yet) no geochronological evidence of a Makkovikian component. Field relationships and geochronological data suggest that its emplacement post-dated Labradorian deformation and metamorphism (Wardle et al., 1986).

Geological Relationships : To the north, the TLGB is in contact with older supracrustal rocks and gneisses of the Makkovik and Churchill Provinces. In central and western Labrador (within the Grenville Province), this contact is mostly a thrust fault of probable Grenvillian age; in eastern Labrador (outside the Grenville Province), it is an intrusive contact (Wardle et al., 1986). The TLGB is bounded to the south by the Labradorian high-grade terranes; this contact is generally a thrust, and corresponds with a rapid increase in metamorphic grade and deformation state (Gower and Owen, 1984; Wardle et al., 1986). Orthogneiss assemblages, and gabbroic to granitoid intrusive rocks within the high-grade terranes, are probably equivalent to the less deformed parts of the TLGB to the north, and some yield U-Pb zircon crystallization ages of 1670 - 1630 Ma (Schärer et al., 1986; Schärer and Gower, 1988). The original width of the TLGB was probably greater than it now appears, due to shortening during later deformation.

Plutonic Assemblages : The TLGB in eastern Labrador is
divided in this study into Makkovikian and Labradorian
plutonic assemblages. These terms refer broadly to periods
of time from 1860 to 1750 Ma (c.f. Gower and Ryan, 1986;
see below) and 1700 to 1600 Ma (Thomas et al., 1986)
respectively. The minimum age for the Makkovikian
assemblage differs from the 1790 Ma limit suggested by
Gower and Ryan (1986), as there is evidence that
Makkovikian plutonism continued until at least 1750 Ma, and
possibly beyond (Krogh et al., in prep.).

Makkovikian plutonic rocks are further subdivided into
syn-tectonic and post-tectonic associations. These are
compositionally similar and are regarded by the author as
closely related. Rb-Sr (this study) and U-Pb (Krogh et al.,
in prep.) data indicate that they are also partly of
similar age. The distinction is convenient for descriptive
purposes, although the syn- and post-tectonic aspects may
simply reflect heterogeneous Makkovikian deformation,
rather than a significant difference in emplacement age.

2.2 GEOLOGY OF THE MAKKOVIK PROVINCE AND ADJACENT AREAS

The geological evolution of the Makkovik province is depicted in simplified form in Table 2.1. For the purposes of description, it is subdivided into several lithological packages, which are indicated on a simplified geological map (Figure 2.3).

Archean Rocks

Archean gneisses are exposed in the northwest of the Makkovik Province, and in the adjacent Nain Province (Ryan et al., 1983; Korstgård and Ermanovics, 1985). They represent probable basement material for the western portion of the study area. They comprise banded quartzofeldspathic orthogneiss (possibly as old as 3100 Ma; Loveridge et al.,1987), containing lenses of older amphibolite and paragneiss. These orthogneisses are intruded by sodic granitoid rocks dated at ca. 2800 Ma (Loveridge et al., 1987), and by several generations of mafic dykes. In the Makkovik Province, all of these rocks have been affected by Lower Proterozoic orogenic events termed the Makkovikian orogeny (Gower and Ryan, 1986), and possibly also by earlier events. The degree of metamorphic and structural reworking of the Archean increases from northwest to southeast towards Kaipokok Bay (Ryan and Kay, 1982). Small areas of similar gneisses occur southeast of Kaipokok Bay, associated with the Aillik Group (see below). These are undated, but are presumed to be Archean (Gower et al., 1982).

Bay of Islands

Makkovik Bay

Adlavik Islands

Ragged Islands

Cape Harrison

Kaipokok Bay

Adlavik Bay

Tukialik Bay

Jeanette Bay

Fault Zone

Adlavik Brook

Big River

Benedict Fault Zone

Lake Michael

QUEBEC

LABRADOR

200 km

0 25
Kilometres
0 25

N

LEGEND

PLUTONIC IGNEOUS ROCKS

POST-LABRADORIAN PLUTONIC ROCKS

■ Michael Gabbro Suite.

— — —Major Fault (approximate)

∿ Geologic Contact (approximate)

TLGB

▨ Plutonic rocks of uncertain age and affinity.

LABRADORIAN PLUTONIC ROCKS

▨ Granitoid Rocks (mostly quartz monzonite to granite).

▨ Gabbro and diorite (includes Adlavik Intrusive Suite).

MAKKOVIKIAN PLUTONIC ROCKS

▨ Massive, post-tectonic quartz monzonite to granite.

▨ Foliated, possibly syn-tectonic quartz monzonite to granite. May include some pre-Makkovikian material.

SUPRACRUSTAL SEQUENCES

▨ Bruce River Group: sandstone, conglomerate, arkose, mafic to felsic volcanics.

▨ Upper Aillik Group: predominantly felsic volcanics with minor metasedimentary rocks.

▨ Moran Lake Group and Lower Aillik Group: metasedimentary rocks and mafic metavolcanic rocks.

ARCHEAN BASEMENT ROCKS

▢ Quartzofeldspathic banded orthogneiss, amphibolite, foliated granitoid rocks.

METAMORPHIC ROCKS

▨ Granitoid Gneisses of The Grenville Province: foliated granites and gneisses, probably deformed and reworked equivalents of Makkovikian and Labradorian plutonic rocks.

▨ Cape Harrison Metamorphic Suite: tonalitic gneisses and foliated granitoid rocks of Makkovikian or pre-Makkovikian age.

Figure 2.3. Generalized geological map of the Makkovik Province and adjacent areas of Labrador. Geology compiled from Gower (1981), Gower et al.(1982), Ryan (1984), Ryan et al. (1983) and Kerr (1986, 1987, 1988).

Cape Harrison Metamorphic Suite

The Cape Harrison Metamorphic Suite (Gower, 1981) is the oldest recognized component in the eastern part of the study area (Figure 2.3). It consists of massive to banded orthogneiss, ranging in composition from diorite to granodiorite, with lesser amounts of foliated granodiorite and granite. In terms of field appearance, it resembles the Archean gneisses in many respects. Brooks (1983) obtained a Rb-Sr errorchron age of 1740 ± 85 Ma, with a low initial ratio of 0.7034 that apparently precludes extensive crustal prehistory. Nd isotopic compositions (Chapter 9; Kerr and Fryer, in press) also indicate that the suite is unlikely to be older than 2100 Ma, and must therefore represent Proterozoic material which has undergone a period of high-grade metamorphism not recorded by adjacent Makkovikian plutonic rocks. It is thus the only candidate for pre-Makkovikian basement in the eastern part of the study area.

Moran Lake Group and Lower Aillik Group

The Moran Lake and Lower Aillik Groups are Early Proterozoic supracrustal rocks of uncertain age that are dominated by sedimentary and mafic volcanic rocks. The Moran Lake Group (Ryan, 1984) rests unconformably upon Archean gneisses in the west of the Makkovik Province. It consists of a lower sedimentary sequence including quartzite, shale, dolostone and iron formation, overlain by mafic volcanic rocks. It has been metamorphosed to greenschist facies, and is moderately deformed.

The Lower Aillik Group (described by Gandhi, 1978; Gower et al., 1982) is exposed in a zone of intense folding

and thrusting along Kaipokok Bay and consists of arenaceous
to pelitic metasedimentary rocks overlain by mafic
metavolcanic rocks. It is at least 1860 Ma old, based on
U-Pb ages from an overlying sequence and granitoid plutons
that intrude it (see below). The contact between the Lower
Aillik Group and the Archean is a mylonite zone (Marten,
1977), and a number of similar structures (interpreted as
slides or thrusts) occur in higher parts of the sequence.
It may have been deposited as a cover sequence upon the
Archean, but no unconformity is preserved. The Lower Aillik
Group was metamorphosed to amphibolite facies, and
underwent several phases of folding (Marten, 1977; Gower et
al., 1982).

The similarity in stratigraphy and setting of the Moran
Lake and Lower Aillik Groups suggests that they are equivalent
(Wardle and Bailey, 1981; Gower and Ryan, 1986).

Upper Aillik Group

The Upper Aillik Group (described by Gandhi, 1978 and
Gower et al., 1982) consists of felsic volcanic and
volcaniclastic rocks, related volcanogenic sedimentary
rocks and subvolcanic intrusions. The volcanic rocks yield
U-Pb zircon ages of ca. 1860 and 1807 Ma (Schärer et al.,
1988), suggesting at least two episodes of volcanism. The
relationship between Lower and Upper Aillik Groups is
unclear; their mutual contact is a mylonite zone that may
represent a modified unconformity (Marten, 1977).

The stratigraphy of the Upper Aillik Group is poorly
known; in general terms, it consists of a lower sequence of
sandstone, arkose, conglomerate and tuff overlain by a
massive accumulation of dacitic to rhyolitic flows and

Table 2.1. Summary of the geological evolution of the Makkovik Province

TIMING	DESCRIPTION OF EVENT(S)
< 1000 Ma	Emplacement of mafic dykes of several ages, deposition of Late Proterozoic Double Mer Formation in rift or graben basins of the Lake Melville area.
1200 - 1000 Ma	GRENVILLIAN OROGENY - Thrusting and metamorphism south of Grenville Front Zone, minor effects in Makkovik Province.
1450 - 1300 Ma	Emplacement of Michael Gabbro Suite (ca. 1430 Ma). Minor gabbro to syenite intrusions in adjacent Labradorian high-grade terranes. Emplacement of anorthosite-granite intrusions in Nain and Churcill Provinces.
1670 - 1600 Ma	Emplacement of Labradorian plutonic rocks (gabbro, diorite and granitoids). Extrusion of Bruce River Group volcanic rocks and possibly some volcanic rocks in Makkovik Province. Emplacement of ca. 1.65 Ga plutonic rocks following deformation/metamorphism in adjacent high-grade terranes.
1800 - 1750 Ma	Emplacement of post-tectonic Makkovikian intrusive rocks (quartz monzonite to granite), possibly coeval with localized late deformation (see below). Extrusion of parts of the Upper Aillik Group felsic volcanic sequence.
1850 - 1800 Ma	Emplacement of syn-tectonic and late-tectonic Makkovikian plutonic rocks (quartz monzonite to granite). Some of these are similar in age to undeformed Makkovikian granitoids, suggesting that deformation may have been heterogeneous. Extrusion of parts of the Upper Aillik Group sequence.
ca. 1860 Ma	Extrusion of earliest known volcanic rocks in the Upper Aillik Group.
?	Deformation and metamorphism of Lower Aillik Group. This may postdate deposition/extrusion of earliest Upper Aillik Group.
ca. 1900 Ma	Emplacement of poorly known pre-Makkovikian granitoid rocks. May predate deposition of Moran Lake - Lower Aillik Group.
2000 - 1860 Ma	Deposition of sedimentary and volcanic rocks of the Moran Lake Group and Lower Aillik Group.
?	Migmatization of Archean basement rocks (poorly defined).
2500 - 2000 Ma	Emplacement of mafic dyke swarms into Archean gneiss complex.
2800 - 2500 Ma	Stabilization of Archean gneiss complex.

pyroclastic rocks (Gower and Ryan, 1987). The sequence is variably metamorphosed, but is generally at or below greenschist facies; some parts of the sequence show little or no evidence of deformation. Volcanic sequences in the east of the study area are included with the Upper Aillik Group in Figure 2.3 but may represent a younger sequence (see discussion in Chapter 7). The Upper Aillik Group overlaps partly in age with the TLGB Makkovikian assemblage (see below), and is regarded partly as a Makkovikian volcanic sequence (c.f. Gower and Ryan, 1987; see Chapter 7 for discussion).

Syn-Tectonic Makkovikian Plutonic Rocks

These granitoid plutons have NE or NNE-trending fabrics. They intrude the Archean gneisses, Lower Aillik Group and parts of the Upper Aillik Group, but share their general structural trends. They are therefore syn-tectonic with respect to deformation during the Makkovikian orogeny (Marten, 1977). U-Pb zircon, Rb-Sr and K-Ar ages from these rocks are mostly between 1840 and 1800 Ma (Loveridge et al., 1987; Gandhi et al., 1988; Krogh et al., in prep.). They include quartz monzonite, granodiorite and fluorite-bearing granite south of Kaipokok Bay, and a large, complex, polyphase tonalite-granite body that intrudes the Archean gneisses north of Kaipokok Bay. Gandhi et al. (1988) and Brooks (1983) report ages greater than 1900 Ma from poorly-known foliated granites to the west of the study area. The extent and significance of this earlier (pre-Makkovikian) magmatism is presently unclear.

Post-Tectonic Makkovikian Plutonic Rocks

These are massive, unfoliated plutonic rocks that intrude the Upper Aillik Group. They comprise monzonite - quartz monzonite - syenite intrusions, and granite to alkali-feldspar granite, commonly fluorite-bearing. Rb-Sr (this study) and U-Pb (Krogh et al., in prep.) ages of ca. 1800 Ma are similar to those from some of their syn-tectonic counterparts (see above), and it is likely that both groups represent a single pulse of magmatism that transcended late Makkovikian deformation. Some members of this group may, however, be as young as ca. 1760 Ma. In the south of the area, these rocks have east-west structural trends that were imposed by the Grenvillian Orogeny.

Labradorian Plutonic Rocks

The TLGB Labradorian assemblage consists entirely of undeformed plutonic rocks that intrude the Upper Aillik Group and Makkovikian plutonic rocks. They include layered gabbro - monzonite - syenite intrusions, regionally extensive quartz monzonite to granite, and small leucocratic granite plutons. U-Pb zircon ages (Brooks, 1983; Krogh et al., in prep.) are between 1670 and 1630 Ma, but cluster around 1650 Ma. In the south of the area, these rocks have east-west structural trends that were imposed by the Grenvillian Orogeny.

Unclassified Plutonic Rocks

There are no field criteria for separation of post-tectonic Makkovikian and Labradorian assemblages. Several units are therefore unclassified at present. These range in composition from quartz monzonite to granite.

- 42 -

Bruce River Group

The Bruce River Group (Ryan, 1984; Ryan et al., 1987)
is a supracrustal sequence in the west of the area depicted
in Figure 2.3, but outside the confines of the study area.
It rests unconformably upon the Moran Lake Group, and has
suffered only minimal (Grenvillian) deformation and
metamorphism. It consists of arkose, conglomerate and
sandstone, overlain by a thick (8 km) accumulation of mafic
to felsic volcanic and pyroclastic rocks. U-Pb zircon
dating (Schärer et al., 1988) indicates an age of ca. 1649
± 1 Ma, in contrast to previous Rb-Sr ages of ca. 1530 -
1510 Ma (Kontak, in Ryan, 1984). It is thus regarded as a
volcanic sequence equivalent to the TLGB Labradorian
assemblage (after Ryan, 1984; see Chapter 7 for
discussion).

Michael Gabbro Intrusions

Small bodies of mafic intrusive rocks (Michael Gabbro)
are widespread in the southern part of the Makkovik
Province and adjacent Grenville Province. They consist of
olivine-gabbro and gabbronorite emplaced ca. 1425 Ma (U-Pb
zircon; Schärer et al., 1986), and have variably developed
coronitic structures that record the effects of Grenvillian
metamorphism or metamorphic conditions at the time of their
emplacement (Gower, 1986).

Granitoid Gneisses Of The Grenville Province

The Grenville Front Zone is represented in the study
area by the Benedict fault system (Figure 2.3; see below).
The area south of the fault is dominated by deformed

granitoid rocks and granitoid gneisses with relict
porphyritic (i.e. augen) textures and cataclastic fabrics.
These are associated with fine-grained, banded, mylonitic
rocks. These gneisses are probably reworked equivalents of
the granitoid intrusive rocks of the Makkovik Province
(Gower and Owen, 1984), but Makkovikian and Labradorian
components cannot be discerned. The granitoid gneisses are
thus described in conjunction with unclassified plutonic
rocks (see above). Deformed (variably coronitic) intrusions
of the Michael Gabbro Suite (see above) are most common
south of the Benedict fault system.

Structural and Metamorphic Patterns

Structural Trends : The structure of the study area
has been discussed by Gower et al.(1982), Ryan (1984),
Clark (1973,1979) and Marten (1977). It is dominated by two
major structural trends (Figure 2.3). The older trend has a
NE or NNE orientation, and is typified by the fold and
thrust belt along Kaipokok Bay. This trend is present also
in syn-tectonic Makkovikian plutonic rocks. It represents
structures developed during the Makkovikian orogeny at or
before ca. 1800 Ma ago (Gower and Ryan, 1986). Major faults
associated with this trend include slide and thrust zones
in the Lower Aillik Group (Marten, 1977).

The second trend is of broadly east-west orientation,
and is probably related to the Grenvillian Orogeny at ca.
1100 Ma. The NE to NNE "Makkovikian trend" and the E to ENE
"Grenvillian trend" are distinct in the east and north of
the area, but their discrimination becomes more difficult
in the south-west, where both trends converge into a
general NE direction (Figure 2.3). There is no evidence of
Labradorian (ca. 1650 Ma) deformation in the study area.

The Grenvillian trend is most strongly developed south of the Benedict fault system, but several fault zones in the Makkovik Province share its general orientation.

Major Faults : A number of major east-trending faults divide the area into structural blocks. The most important is the Benedict fault system, which is the locus of the Grenville Front Zone (Gower et al., 1980). This is probably a high-angle reverse or thrust fault (Gower, 1981; Owen et al., 1986). The subparallel Adlavik Brook fault system (Gower et al., 1982) has a transcurrent displacement of ca. 20-30 km. This fault marks the northern limit of recognisable Grenvillian deformation. The area between these two fault systems is characterized by local, strongly foliated to cataclastic, zones subparallel to the major faults. It is dominated by areally extensive "regional" granitoid units (Kerr, 1987). North of the Adlavik Brook fault system , the Upper Aillik Group is areally dominant, and TLGB plutonic rocks occur as discrete, isolated bodies. The distribution and characteristics of these plutonic rocks suggest that the upper surface of the TLGB is close to the erosion surface in this area.

Contrasts across the Benedict and Adlavik Brook fault systems are interpreted to reflect differences in crustal levels imposed by reverse faulting and thrusting during the Grenvillian Orogeny (Gower and Ryan, 1986; Kerr, 1987 ; Owen et al., 1988), which exposed progressively deeper levels of the crust in the south.

Metamorphism : Metamorphic events correspond to development of Makkovikian and Grenvillian structural trends. Makkovikian metamorphism affected the Archean

gneisses, Aillik Group and syn-tectonic Makkovikian
plutonic rocks. In the Lower Aillik Group, upper
amphibolite facies conditions were attained, and pelitic
rocks were partially melted. The Upper Aillik Group ranges
from greenschist to lower amphibolite facies, with a
regional decrease in grade from northwest to southeast
(Gower et al., 1982). Foliated granitoid rocks are variably
recrystallized, but most retain relict igneous mineral
assemblages, suggesting that their emplacement post-dated
the peak of metamorphism. Grenvillian metamorphism is
prevalent south of the Adlavik Brook fault zone, and is
manifested by recrystallization, strain, and variable
retrogression of igneous mineral assemblages in all
components of the TLGB. These effects become stronger
within the Grenville Province, but relict igneous textures
are locally visible well to the south of the Benedict fault
system.

Contact metamorphic effects associated with plutonic
rocks of the TLGB appear minor; this is probably a function
of the unreactive quartzofeldspathic compositions of the
Upper Aillik Group felsic volcanic rocks that form the
dominant country rocks. In areas adjacent to plutonic
rocks, these are commonly saccharoidal in texture,
suggesting static, thermal recrystallization of quartz and
feldspar.

2.3 STRATIGRAPHIC GROUPINGS AND TERMINOLOGY

General Information

Makkovikian and Labradorian plutonic assemblages are each divided into a number of units and intrusive suites. New names are proposed for some of these divisions (Table 2.2). This terminology is introduced here to familiarize the reader prior to definition and description of these associations in subsequent chapters. Locations of units and divisions in Table 2.2 are shown on the 1:250,000 geological map (enclosure) and in summary location maps at the start of the relevant descriptive chapters.

Intrusive Suites and Units

The term "intrusive suite" is used in two senses. Firstly, it is used to group geographically discrete units that are closely similar in petrology and geochemistry. These geographically discrete units have generally been given individual names. Secondly, it is used to group units of differing composition that are spatially and genetically related. In the latter case, individual units are generally not named. This corresponds with conventional use and with suggestions made by Salvador (1987) and Bateman (1988) for the International Subcommission on Stratigraphic Conventions. In descriptions of units and suites in subsequent chapters, the qualifier "intrusive" is sometimes omitted for the sake of brevity.

	Intrusive Suite	Unit(s)	(best data)	Comments
LABRADORIAN ASSEMBLAGE	not named	Otter Lake - Walker Lake Granitoid (name after Ryan, 1984)	1647 +/- 2 Ma (U-Pb zircon) (Krogh et al., in prep.) 1550 +/- 55 Ma (Rb-Sr WR) (Kontak, in Ryan, 1984)	Regionally extensive unit ranging in composition from quartz monzonite to granite.
	Monkey Hill* Intrusive Suite	Monkey Hill Granite* Little Monkey Hill Granite* Duck Island Granite* Bent's Cove Granite* Round Pond Granite Kidlaluit Granite*	Monkey Hill Granite : 1640 +/- 10 Ma (U-Pb zircon) (Krogh et al., in prep.) Round Pond Granite : 1620 +/- 60 Ma (K-Ar biotite) (Wanless et al., 1970)	Consists of a number of small, epizonal plutons comprising fine-grained leucogranite. Little Monkey Hill Granite Cuts gabbro and diorite of Adlavik Intrusive Suite.
	not named	Burnt Lake Granite Witchdoctor Granite*	1548 +/- 90 Ma (Rb-Sr WR) (MacKenzie and Wilton, 1988) 1632 +/- 9 Ma (U-Pb zircon) (Brooks, 1983)	Leucocratic granite units, probably two phases of the same body. Locally similar to Monkey Hill Intrusive Suite granites.
	Mount Benedict* Intrusive Suite	(units not named) Gabbro to diorite unit Monzonite to syenite unit Syenite to granite unit	1650 +/- 10 Ma (U-Pb zircon) (Krogh et al., in prep.) 1625 +/- 50 Ma (Rb-Sr, w.r.) (Brooks, 1983)	Layered assemblage, diorite and gabbro at base, evolved syenite at the top. Gabbro and diorite are very similar to Adlavik Intrusive Suite.
	Adlavik Intrusive Suite	(units not named) Diorite to Monzonite unit Gabbro and leucogabbro unit	1649 +/- 1 Ma (U-Pb zircon) (Krogh et al., in prep.)	Polyphase layered mafic intrusion, evolving to diorite and monzonite. Parts of suite resemble Mount Benedict Suite.
MAKKOVIKIAN ASSEMBLAGE (POST-TECTONIC ASSOCIATION)	not named	Big River Granite*	1798 +/- 28 Ma (Rb-Sr WR) (this study)	Regionally extensive granite unit with mantled-fsp texture.
	Strawberry* Intrusive Suite	Bayhead Granite* Cape Strawberry Granite October Harbour Granite Dog Islands Granite* Tukialik Granite*	Preliminary Data (discordant): 1800 to 1760 Ma (U-Pb zircon) (Krogh et al., in prep.) 1694 +/- 56 Ma (Rb-Sr WR) (this study)	Array of epizonal plutons of closely similar, coarse grained biotite granite, commonly K-fsp porphyritic, and fluorite-bearing.
	Lanceground * Intrusive Suite	Lanceground Hills Granite* Pistol Lake Granite Tarun Granite*	Lanceground Hills Granite : 1692 +/- 32 Ma (Rb-Sr WR) (this study) [Age is considered disturbed]	Coarse grained, locally hyper-solvus, quartz syenite to granite plutons, with abundant zircon, allanite, fluorite.
	Numok* Intrusive Suite	(units not named) Monzonite to quartz monzonite Syenite to quartz syenite	1801 +/- 2 Ma (U-Pb zircon) (Krogh et al., in prep.)	Coarse grained monzonite to quartz syenite. Some syenitic rocks resemble Lanceground Intrusive Suite.

MAKKOVIKIAN ASSEMBLAGE / **SYN-TECTONIC ASSOCIATION**	not named	Long Island Quartz Monzonite (after Gower et al., 1982)	1802 +13 / -7 Ma (U-Pb zircon) (Gandhi et al., 1988)	Foliated, melanocratic quartz monzonite.
	not named	Melody Granite*	age unknown	Strongly foliated granite
	not named	Brumwater Granite Pitre Lake Granite Manak Island Granitoid*	ages unknown, but foliation suggests > 1800 Ma for all.	Small, leucocratic granitoid units.
	not named	Deus Cape Granitoid*	1837 +6 / -4 Ma (U-Pb zircon) (Krogh et al., in prep.)	Part of a regionally extensive unit exposed east of study area.
	Kennedy Mountain* Intrusive Suite	Kennedy Mountain Granite* Narrows Granite* Cross Lake Granite* Other (not named)	1778 +/- 98 Ma (Rb-Sr WR) (this study) [age considered disturbed]	Coarse grained, foliated, K-fsp porphyritic granite, commonly fluorite-bearing.
	Island Harbour Bay Intrusive Suite (after Ryan et al.,1983)	(units not named)	1805 +/- 5 Ma (U-Pb zircon) (Loveridge et al., 1987) (coarse-grained granite only)	Complex, polyphase tonalite to granite intrusion emplaced into Archean gneiss complex.
UNCLASSIFIED PLUTONIC ROCKS	not named	Freshsteak Lake Granitoid* Noarse Lake Granitoid*	Freshsteak Granitoid : 1798 +/- 48 Ma (Rb-Sr WR) (this study)	Closely similar melanocratic quartz monzonite to monzogranite. probably Makkovikian age.
	not named	Stag Bay Granitoid*	1714 +/- 44 Ma (Rb-Sr WR) (this study)	Affinity uncertain.
	not named	Thunder Mountain Syenite* Jeanette Bay Quartz Syenite*	undated	Small, massive syenitic bodies of uncertain affinity.
		Granitoid gneisses South of Benedict Fault Zone	undated	Probably represents deformed equivalents of both Makkovikian and Labradorian assemblages.

Table 2.2. Summary of stratigraphic terminology employed in this thesis.
New names are indicated by (*).

- 48 -

CHAPTER THREE
SYN-TECTONIC MAKKOVIKIAN
PLUTONIC ROCKS

Chapter Abstract

Syn-tectonic Makkovikian plutonic rocks have regionally developed north or northeast-trending foliations that indicate imposition of at least some Makkovikian deformation upon them. U-Pb zircon ages indicate emplacement between 1840 and 1800 Ma ago. They are divisible into two principal associations on both geological and geochemical grounds.

The first (areally dominant) association is formed by the Long Island Quartz Monzonite, granites of the Kennedy Mountain Intrusive Suite, and the Melody Granite. The first two are homogeneous, regional units that show sharp, intrusive contacts with their country rocks, and appear to have source regions well below the present level of exposure. They range in composition from quartz monzonite to alkali-feldspar granite, are commonly plagioclase and/or K-feldspar porphyritic, and show increasing biotite/hornblende ratios with differentiation. Leucocratic (alaskitic) granites of the Kennedy Mountain Suite are honblende-free and fluorite-bearing. In geochemical terms, this association is metaluminous to weakly peralkaline, and shows enrichment in fluorine, Zr, Y and REE. Trace element trends are consistent with evolution via plagioclase ± K-feldspar fractionation. High HFS and REE contents indicate a source enriched in these elements, and also reflect the role of fluorine in retarding crystallization of accessory minerals. The Kennedy Mountain Suite has undergone local alkali-metasomatism. This is correlated with similar geochemical disturbance reported from felsic volcanic rocks of the Upper Aillik Group, which may be partly equivalent to these plutons. This disturbance has affected LFS trace element patterns, but had little effect on HFS elements and REE. The Melody Granite resembles the Kennedy Mountain Suite in most respects, but displays more intense deformation and hematization.

In contrast, two small intrusions near Kaipokok Bay (Brumwater and Pitre Lake Granites) appear to have been derived by anatectic melting of local country rocks at or slightly below the present level of exposure. Their contacts are diffuse, and

they contain abundant gneissic and metasedimentary xenoliths respectively. They are variably peraluminous in composition, and have low levels of Zr and REE that suggest residual hornblende, zircon or sphene in their source regions. The Pitre Lake Granite shows LREE depletion suggesting residual monazite or allanite in its source, and F and Li enrichment suggesting muscovite breakdown. The Manak Island Granitoid is geochemically similar to the Brumwater Granite, and may have had a similar origin.

A large, composite plutonic body to the north of the study area (Island Harbour Bay Intrusive Suite) appears to contain elements of both settings, as it has a partially migmatitic exterior, but a homogeneous core. It also contains tonalitic and trondhjemitic rocks, that are atypical of intrusions within the study area. Such compositions appear to preclude complete derivation by anatexis of older sialic crust, although such material may have contributed partly to the magmas.

In summary, although anatexis of local country rocks was important in the Kaipokok Bay area, where metamorphic grade is highest, major syn-tectonic Makkovikian plutons mostly came from deeper sources and evolved by fractional crystallization. The character of this magmatism in the study area is granitic, with only minor quartz monzonite to granodiorite.

Introduction

Syn-tectonic Makkovikian plutonic rocks are those
that have north to northeast-trending foliations similar in
orientation to structural trends within the Aillik Group.
They have thus experienced at least the latest period(s) of
Makkovikian deformation. The label "syn-tectonic" is
therefore applied to these rocks. It is recognized,
however, that the contrast in deformation state between
these rocks and their "post-tectonic" Makkovikian
counterparts (Chapter 4) may reflect heterogenous
deformation, rather than significant age differences
between them.

Syn-tectonic Makkovikian plutonic rocks are mostly
located in the north-west of the study area (Figure 3.1).
The most areally extensive units are the Long Island Quartz
Monzonite, Kennedy Mountain Intrusive Suite and Melody
Granite. Two units in the Kaipokok Bay area (Brumwater and
Pitre Lake Granites) are of limited extent, but show
critical field relationships with deformed Archean gneisses
and supracrustal rocks. Foliated granites also occur
locally in the east of the study area (Deus Cape and Manak
Island Granitoids).

The largest single member of this association is the
Island Harbour Bay Intrusive Suite (Ryan et al., 1983),
which intrudes Archean rocks north of Kaipokok Bay, and is
outside the study area. Key field and petrographic
characteristics of all units (excluding the Island Harbour
Bay Suite) are summarized in Table 3.1.
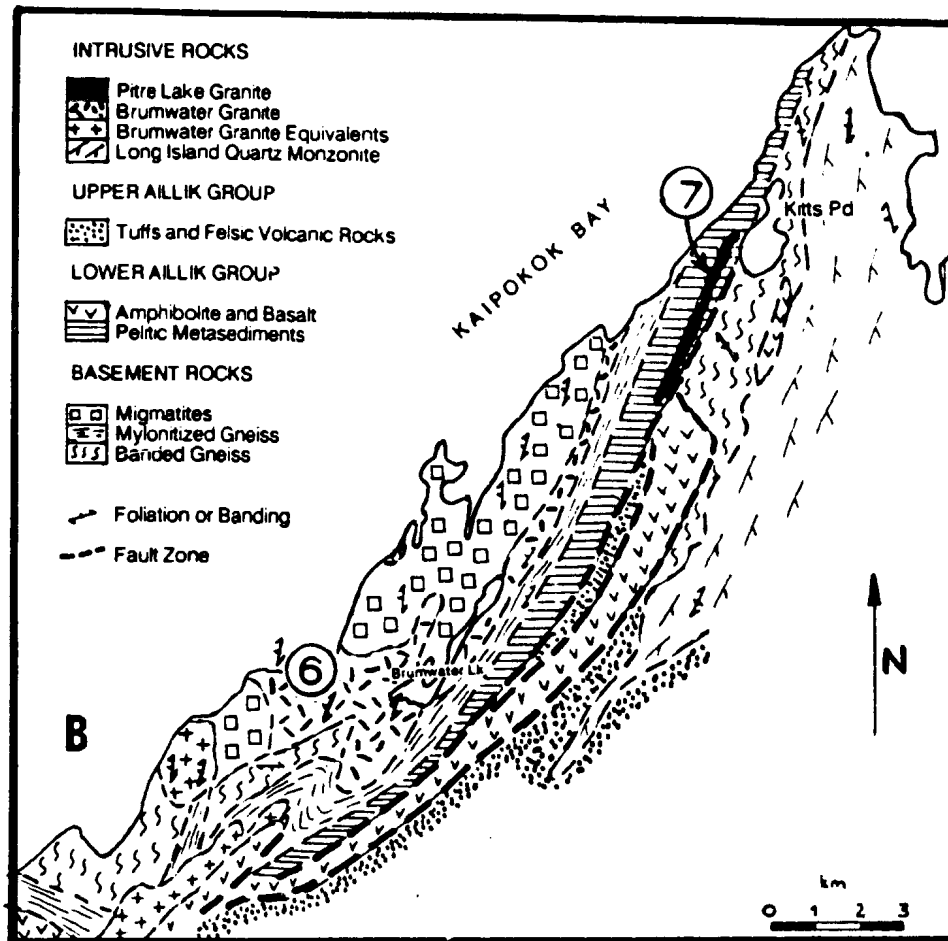
Figure 3.1 (INSET). Geology of part of the eastern side of Kaipokok Bay, showing the location and setting of the Brumwater and Pitre Lake Granites. After Marten (1977) and Gower et al.(1982).

55°30'N

59°00'W

QUEBEC

LABRADOR

200 km

Turnavik Islands

Bay of Islands

Km

N

Archean Gneiss Complex

Aillik Group (undivided)

Adlavik Islands

Ragged Islands

Cape Harrison

Big Bight

Adlavik Bay

Tukialik Bay

Jeanette Bay

Kaipokok Bay

Makkovik Bay

Adlavik Brook

Fault Zone

Benedict Fault Zone

KEY TO UNITS (Map Number in Parentheses)

Melody Granite (5)

Brumwater Granite (6)

Pitre Lake Granite (7)

Manak Island Granitoid (8)

Deus Cape Granitoid (9)

Fault Zone

Long Island Quartz Monzonite (1)

KENNEDY MOUNTAIN INTRUSIVE SUITE
Kennedy Mountain Granite (2)
Narrows Granite (3)
Cross Lake Granite (4)

CAPE HARRISON METAMORPHIC SUITE (10)

ISLAND HARBOUR BAY INTRUSIVE SUITE (11)

A

- 53 -

Figure 3.1.   Summary map illustrating the distribution and extent of
syn-tectonic Makkovikian plutonic rocks. Inset is an enlargement of
the east side of Kaipokok Bay, and illustrates location and setting of
Brumwater and Pitre Lake units. Geology in inset after Marten (1977)
and Gower et al. (1982).

Table 3.1. Key features of syn-tectonic Makkovikian plutonic rocks.

Map Unit	Suite/Unit/Age	General Characteristics	Textural Characteristics
10	Long Island Quartz Monzonite 1832 +/- 58 [K/Ar biotite] 1802 +13/-7 [U-Pb zircon] (Gandhi et al., 1969; 1988)	Grey, melanocratic, foliated Hb-Bi quartz-monzonite to monzogranite. Fabric is strongly developed in marginal portions; core is less deformed. Contains deformed xenoliths of dioritic material.	Fine to medium grained, porphyritic with plag phenocrysts up to 1 cm diameter. Fabric defined by Hb-Bi aggregates, flattened phenocrysts and inclusions. Schlieric to banded near margin.
11 11.1 11.2 11.3 11.4	KENNEDY MOUNTAIN INTRUSIVE SUITE [including] Kennedy Mountain Granite Narrows Granite Cross Lake Granite Unnamed minor bodies 1531 +/- 38 [K-Ar biotite] 1778 +/- 98 Ma (Rb-Sr WR) [ages are not reliable]	Pink to white or buff, foliated, variably porphyritic, Hb-Bi monzogranite, granite and alkali-feldspar granite. Generally leucocratic, locally alaskitic. NE- trending fabric is obvious in porphyritic / melanocratic types, but diffuse in leucogranites. Locally K-fsp depleted, possibly albitized. Widespread fluorite, particularily in leucocratic variants.	Commonly medium to coarse-grained, with K-fsp and lesser plag phenocrysts, variably augened by fabric. Fabric defined by Hb-Bi-Sph aggregates and/or augen texture. Equigranular, leucocratic variants may appear massive. Unit is generally inclusion-free. pegmatite veining widespread.
12	Melody Granite [? 1910 +/- 10 Ma (U-Pb zircon) ?] (Gandhi et al., 1988) See text for discussion; depends on a rather uncertain correlation	Pink to brick-red, variably porphyritic, strongly foliated, leucocratic granite and alkali-feldspar granite.	Coarse grained, porphyritic to porphyroclastic, with "augen" textures, locally mylonitic. Textural variants are defined by variations in mafic content.
13	Brumwater Granite > 1794 +/- 2 [U-Pb monazite] (Scharer et al., 1988)	Grey to pale pink, foliated to lineated, equigranular, leucocratic biotite-granodiorite and monzogranite.	Medium to coarse-grained, locally porphyritic. Contains gneissic inclusions, locally nebulitic. Fabric defined by Bi aggregates and pegmatitic seams.
14	Pitre Lake Granite (Description partly after Marten, 1977)	White to pale pink or buff, equigranular, foliated Bi-Ms leucogranite forming tabular body within metasedimentary rocks of Lower Aillik Group.	Medium-grained and homogeneous. locally displays ghost layering that defines fold structures. Concordant pegmatite and quartzose segregations.
15	Manak Island Granitoid > 1801 +/- 2 Ma [U-Pb ?] [based on age from Numok Suite] (Krogh et al., in prep.)	White to pale grey, foliated, locally porphyritic, leucocratic Bi-granodiorite to monzogranite.	Medium to coarse-grained and homogeneous; inclusion-free.
16	Deus Cape Granitoid 1837 +6/-4 Ma [U-Pb zircon] (Krogh et al., in prep.)	Grey to pink, porphyritic to megacrystic, foliated Hb-Bi granodiorite.	Commonly K-fsp porphyritic, locally seriate-textured.

Table 3.1 (continued)

Key Field Relationships	Mineralogy	Petrography
Cuts early (D1,D2) structures in Aillik Group and Archean, but has S3 fabric. Intruded by Duck Island Granite of Monkey Hill Intrusive Suite.	Qz (10-20%) Mi (30-40%) Plag (An30; 30-40%) Hb+Bi (10-25% total) Sph/Fe Oxide (1-2%) Accessory Zr, Ap, All	Groundmass Qz-Fsp recrystallized. Plag phenocrysts variably saussuritized, recrystallized and zoned. Hb and Bi present in subequal amounts, recrystallized to aggregates, with Sph, Ep, Chl.
Intrudes supracrustal rocks of Upper Aillik Group, and truncates bedding and early (S1;S2) fabrics. Kennedy Mountain Granite and Narrows Granite are cut by Monkey Hill Granite.	Qz (15-35%) Mi (25-60%) Plag (An20-30; 10-50%) Hb+Bi (1-15% total, normally < 5%) Sph (1-3%) Fl (0-2%) Abundant Accessory Zr, Ap, All	Variably recrystallized, but K-fsp phenocrysts preserved with local interstitial quartz. Mi is patchperthite, with local Na-plag rims. Hb/Bi ratios variable; leucocratic variants are Hb-free. Recrystallization is very strong in fine-grained variants, which are saccharoidal. K-fsp depleted types dominated by Na-plag + Qz.
Contact relations unknown. Unit is bounded by inferred faults and unexposed zones.	Qz (15-40%) Mi (30-65%) Plag (An20-30; 20-40%) Bi+Chl+Ep+Sph (2-7% total) Hb (relict) Accessory All, rare Zr, Fl	Extensively rextallized and mylonitized. Qz, Mi, Plag form ribbons or granular aggregates. Mafic minerals reduced to Chl-Ep-Sph aggregates, with relict Bi +/- Hb. Mi phenocrysts hematized.
Unit intrudes refoliated Archean gneisses with S1/S2 fabric. Fabric in granite considered to be D3 feature. Gradational relationship with migmatitic Archean gneisses.	Qz (15-30%) Mi (25-40%) Plag (An25; 25-40%) Bi (2-7%), rare Muscovite Accessory All, Zr.	Recrystallized, fabric defined by orientation of Bi aggregates.
Truncates S1 or S2 fabrics in Lower Aillik Group, but contains foliation parallel to layering. Contains inclusions of pelitic sediments similar to host rocks.	Qz (20-30%) Mi (30-60%) Plag (An20-30; 20-30%) Ms+Bi (5-10% total, Ms > Bi) Accessory Fl, Tm ?	Recrystallized extensively. Fabric defined by alignment of Bi-Ms aggregates and faint layering.
Probably forms a screen between younger units. Unit is intruded by Gabbro of Adlavik Intrusive Suite, probably also by Mumok Intrusive Suite.	Qz (15-20%) Mi (20-40%) Plag (An25-35; 40-60%) Bi (5%) Accessory Sph, Ap. Rare Zr, All.	All components rextallized to polygonal aggregates. Scattered Mi phenocrysts are preserved.
Lacks polydeformed character of adjacent Cape Harrison Metamorphic Complex.		

3.1 GEOLOGY and PETROLOGY

3.1.1 Long Island Quartz Monzonite

This unit forms an elongate body in the Kaipokok Bay area (Figure 3.1), and was originally termed the "Long Island gneiss" (Gandhi et al., 1969). It is rarely gneissic, and subsequent workers used the term "Long Island Quartz Monzonite" (Gower et al., 1982; Kerr, 1986). Definition and boundaries of the unit remain unchanged from those of Gandhi et al. (1969) and Gower et al. (1982). The unit consists of medium-grained, melanocratic, foliated, hornblende-biotite quartz monzonite, granodiorite and (rare) monzogranite (Table 3.1; Plate 3.1). It is characteristically plagioclase-porphyritic, containing small (1 cm) equant phenocrysts.

A penetrative fabric is strongly developed around its margins, but parts of the interior appear massive. Marten (1977) stated that the unit truncates early (S_1 and S_2) fabrics in surrounding Archean and Aillik Group units, and considered the foliation to be a relatively late (D_3) feature. In the area around Mark's Bight, the unit is disrupted and net-veined by the Duck Island Granite of the Monkey Hill Intrusive Suite (see Chapter 5).

The unit is recrystallized, but igneous textures (e.g. zoned plagioclase phenocrysts) are variably preserved. In the more strongly deformed variants, hornblende and biotite are retrogressed to biotite - chlorite - epidote - sphene aggregates.

The Long Island Quartz Monzonite has been dated at 1832 ± 58 Ma by K-Ar whole-rock methods (Gandhi et al., 1969) and at 1802 + 13/-7 Ma by U-Pb zircon methods (Gandhi et al., 1988). The latter sample also yielded a U-Pb sphene (titanite) age of 1746 ± 2 Ma, which provides a minimum age for deformation and metamorphism.
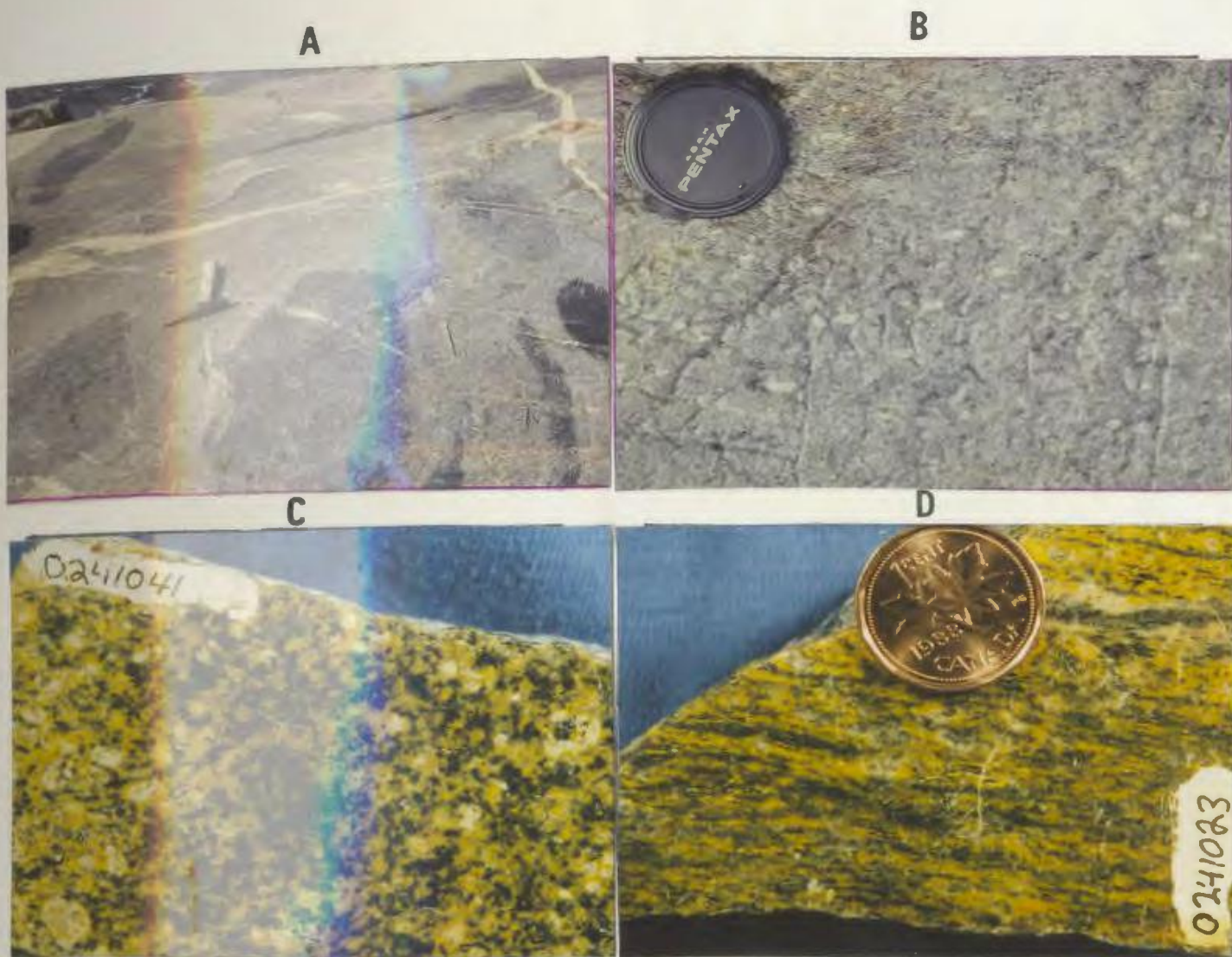
Plate 3.1. Features of the Long Island Quartz Monzonite. (a) Dioritic inclusions (deformed) in grey quartz monzonite, Mark's Bight. (b) Typical weathered surface with plagioclase phenocrysts, Mark's Bight. (c) Massive quartz monzonite from centre of body (phenocrysts ca. 0.5 cm diameter). (d) Strongly deformed variant from eastern margin of body. All slabs stained to turn K-feldspar yellow.

3.1.2 Kennedy Mountain Intrusive Suite

This is a new name introduced for several discrete
bodies of similar foliated granitoid rocks in the Makkovik
Bay area (Figure 3.1). These include units 17a and 17c of
Gower et al. (1982), and foliated granitoid rocks outlined
by Kerr (1986, 1987). The type area (Kennedy Mountain
Granite) corresponds to the Kennedy's Cove "gneiss" of
Clark (1973), but is rarely gneissic. The suite is
dominated by foliated, variably K-feldspar porphyritic,
monzogranite, granite and alkali-feldspar granite, commonly
containing accessory fluorite (Table 3.1; Plate 3.2). The
unit is not dated reliably. Gandhi et al. (1969) obtained a
K-Ar (mixed hornblende and biotite) age of 1531 ± 38 Ma,
which is probably anomalously young. A composite Rb-Sr
isochron (Chapter 8) suggests an age of 1778 ± 98 Ma, but
this is not considered reliable. No U-Pb data are available
as of writing.

Field Relationships : The Kennedy Mountain Granite
and Narrows Granite intrude the Upper Aillik Group, but are
cut by the Labradorian Monkey Hill Granite (Chapter 5).
Units assigned to the suite contain a single NE-trending
foliation; by analogy with the Long Island unit, this is
interpreted to be a D_3 feature resulting from Late
Makkovikian deformation, and implies a similar minimum age of
1800 Ma. Foliations are most obvious in relatively
melanocratic, porphyritic variants, whereas equigranular
and leucocratic variants commonly appear massive and
unfoliated. However, all are recrystallized and display
fabrics in thin section; in leucocratic variants,
orientations are defined by elongation of quartz and
feldspar. Coarse grained, fluorite and/or pyrite-bearing
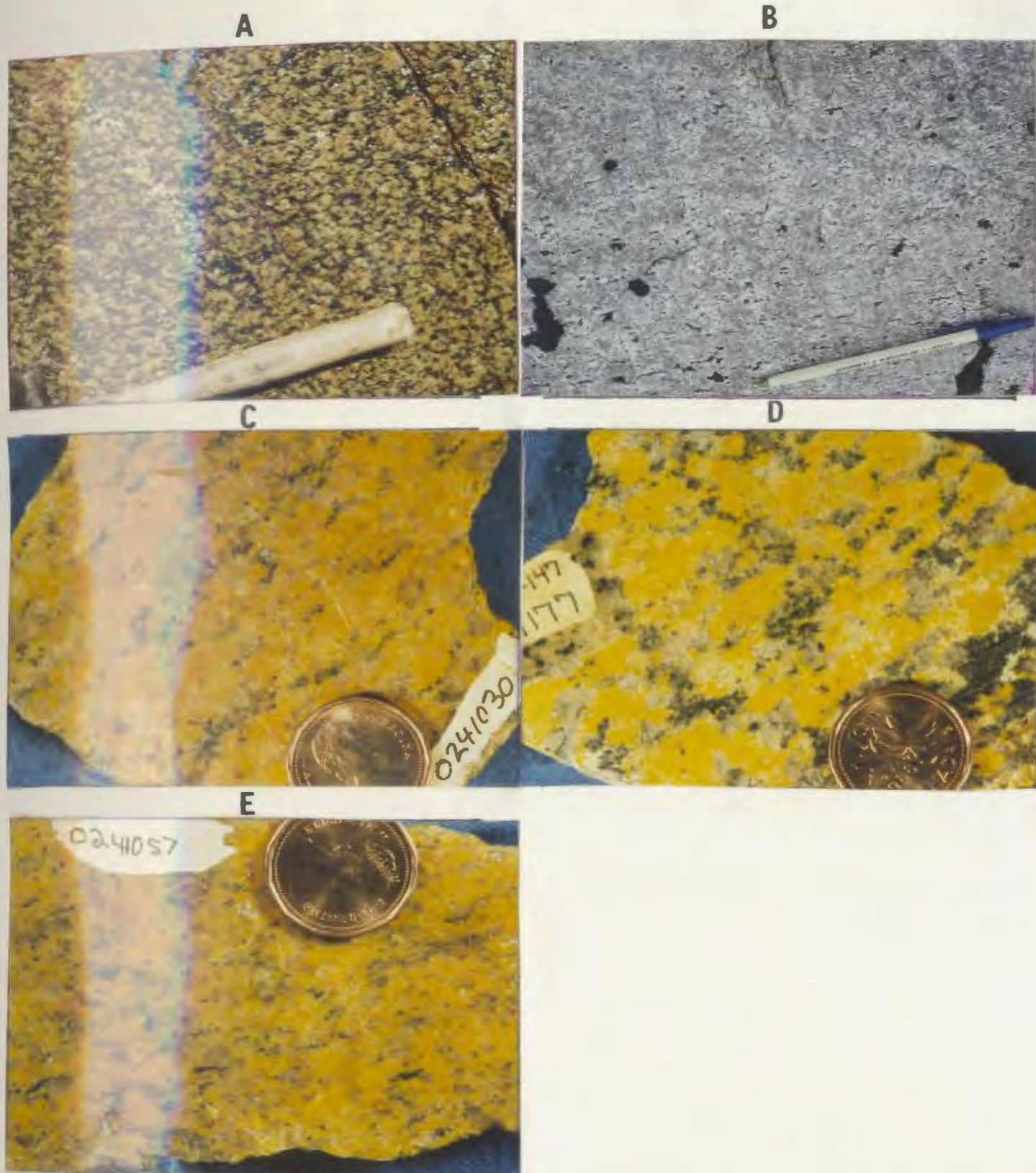
Plate 3.2. Features of the Kennedy Mountain Intrusive Suite. (a) Coarse-grained monzogranite (Narrows Granite, Makkovik Bay). (b) Fine-grained alaskitic variant of the Cross Lake Granite; the superb glacial polish is a reflection of the pervasive recrystallization, which reduces the natural tendency of granite to disaggregate. (c) Fluorite-bearing leucogranite (Kennedy Mountain Granite, Makkovik Bay), foliation is parallel to slab label. (d) Coarse-grained biotite-hornblende granite (Narrows Granite), section cut normal to foliation. (e) Fine-grained potassic leucogranite (Cross Lake Granite). All slabs stained to turn K-feldspar yellow.

pegmatite veins (locally containing amazonite, a green
variety of K-feldspar) intrude many outcrops, particularly
in the Cross Lake Granite. Xenoliths of country rocks are
rare except adjacent to contacts; cognate xenoliths
(normally darker than their host) occur locally. The Cross
Lake Granite appears to be more leucocratic than other
units of the suite, and is locally alaskitic (i.e., a
fine-grained rock consisting essentially of quartz and
alkali-feldspar; Johannsen, 1920).

Petrography : Most examples contain both hornblende
and biotite, but leucocratic variants are hornblende-poor
or hornblende-free. Purple fluorite is widespread
(particularily in leucocratic rocks), and forms coarse
patches along foliation planes. Sphene is also prominent in
many hand samples. In thin section, most examples are
recrystallized, but original igneous textures (K-feldspar
phenocrysts and, more rarely, interstitial quartz) are
variably preserved. Mafic minerals and sphene form
aggregates, associated with prominent and abundant zircon,
allanite, apatite and fluorite crystals. Chlorite and/or
epidote are locally important as alteration products of
hornblende and biotite.

Anomalous rock types consisting almost entirely of
sodic plagioclase (< An_{15}) and quartz are present locally
within all units of the Kennedy Mountain Suite. These are
considered to be Na-metasomatized, rather than original,
compositions (see 3.2 and 3.3). Rare albite rims or patches
on K-feldspar phenocrysts in "normal" variants form the
only petrographic evidence for this process; the
anomalously sodic rocks are thoroughly recrystallized.

3.1.3 Melody Granite

The new name Melody Granite is introduced for an
elongate unit of strongly foliated granitoid rocks in the
western part of the study area (Figure 3.1). The unit is
dominated by pink to brick-red, K-feldspar-rich granite and
alkali-feldspar granite (Table 3.1; Plate 3.3). It
corresponds to parts of unit 14 of Bailey (1979) and parts
of unit 27 of Gower et al. (1982).

Field Relations : The contact relations of the Melody
Granite are unknown, as most of its boundaries correspond
with inferred fault zones or unexposed areas. It has a
widely developed cataclastic to protomylonitic fabric and
commonly shows augen texture. There are two textural
variants, defined by variation in total mafic mineral
content. The melanocratic variants commonly show more
obvious relict porphyritic textures, but leucocratic
variants are also strongly K-feldspar porphyritic where
weakly deformed. The distribution of these two variants
corresponds generally to units 23 and 24 of Ryan (1984),
described as granite and granodiorite respectively

Petrography : In thin section, the Melody Granite is
strongly recrystallized. It displays a granular texture, and
many examples contain quartz and feldspar ribbons, oriented
parallel to microcrystalline mylonitic zones. The mafic
mineral assemblage varies with intensity of deformation and
metamorphism; weakly-deformed samples contain aggregates of
fine-grained green-brown biotite and local relict
hornblende, whereas strongly deformed variants contain only
sphene - chlorite - epidote aggregates along foliation
planes.
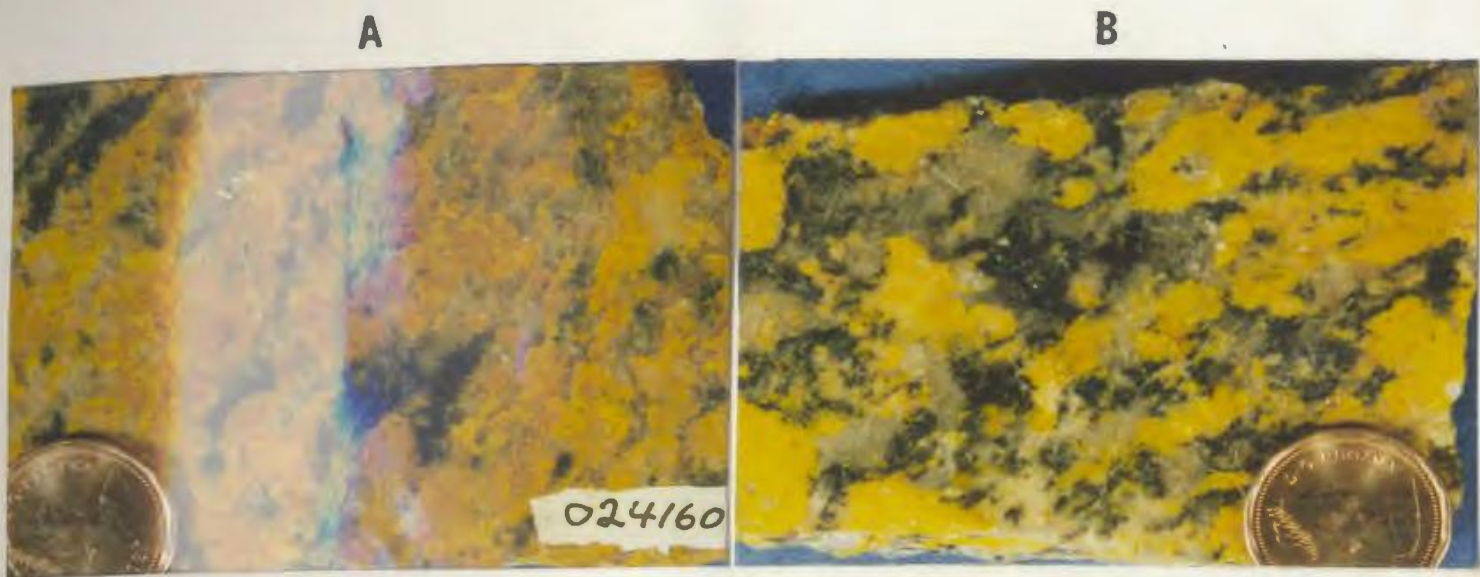
Plate 3.3. Features of the Melody Granite. (a) Strongly deformed granitoid with ribbon quartz and cataclastic texture, but with relict K-feldspar phenocrysts. (b) Weakly deformed, porphyritic, melanocratic variant. All slabs stained to turn K-feldspar yellow.
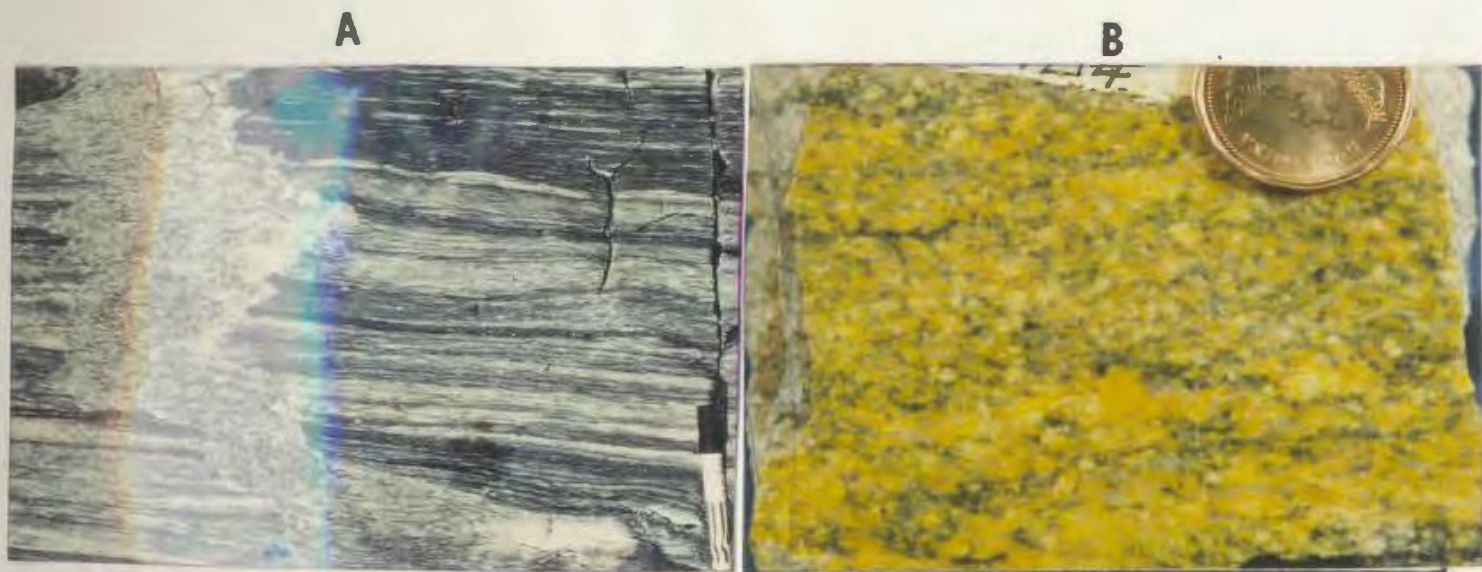
Plate 3.4. Features of the Brumwater Granite. (a) Vein of grey granite cutting refoliated Archean gneiss, Kaipokok Bay area. Note that vein truncates banding, but is affected by later deformation, and shares the same general fabric. (b) Typical stained slab, showing heterogeneous and slightly banded appearance of many examples.

Age Uncertainty : The Melody Granite is undated. Ryan (1984) mapped it as continous with his unit 23, based on compilation of unpublished BRINCO descriptions. Ryan's unit 23 has yielded an age of 1910 ± 10 Ma about 50 km west of the study area (Gandhi et al., 1988). This result may indicate a pre- Makkovikian age for the Melody Granite; however, the correlation is based purely on general lithology, and the author has not examined the sample of Gandhi et al. (1988). For the purposes of the current discussion, therefore, the Melody Granite is regarded as a syr-tectonic Makkovikian intrusion, although this may be subject to revision.

3.1.4 Brumwater granite

The Brumwater granite (Marten, 1977) is a small, tabular body that intrudes reworked Archean basement rocks southeast of Kaipokok Bay (Figure 3.1, inset). It was defined and mapped by Marten (1977), and visited briefly during this project. It consists of grey to pink, foliated, leucocratic, biotite- granodiorite and monzogranite (Table 3.1; Plate 3.4). Marten (1977) describes similar rock types from other parts of the Archean inlier along Kaipokok Bay, which he correlated with the Brumwater Granite (Figure 3.1, inset).

Field Relationships and Age : Marten (1977) described a gradational relationship between this unit and adjacent migmatized Archean gneisses, and suggested that it may be an anatectic derivative of them. Enclaves of gneissic material are locally present, and a "ghost layering" is present in some outcrops. The granite truncates layering in refoliated Archean gneisses that is considered to be a D_2

structure, and foliation in the granite is thus considered
to be a D_3 feature (Marten, 1977). Its relationship to
deformation is therefore analogous to the Long Island
Quartz Monzonite (see above). The foliation is defined by
biotite aggregates and concordant pegmatitic and quartzose
seams. An augen texture is locally developed.

Schärer et al.(1988) obtained a U-Pb monazite age of
1794 ± 2 Ma from a biotite leucogranite that cuts
migmatites correlated with the Brumwater granite; this
provides a lower limit on the age of the unit. An attempt
to date the granite itself failed due to a highly
discordant, U-rich zircon population (U.Schärer, pers.comm.
to R.J.Wardle).

3.1.5 Pitre Lake Granite

The Pitre Lake granite, defined and mapped by Marten
(1977), is a thin, tabular, subconcordant body that is
confined to metasedimentary rocks of the Lower Aillik Group
in the Kitts Pond area (Figure 3.1, inset). It was visited
only briefly during this study. The unit consists of
medium-grained, equigranular biotite-muscovite granite
(Table 3.1; Plate 3.5).

The granite truncates the foliation in the host
metasediments (a composite D_1/D_2 structure; Marten,
1977), but contains a weak to moderate foliation
subparallel to or slightly oblique to its contacts. Marten
(1977) considered this to be a D_3 feature, and suggested
that the unit was a syn-D_3 intrusion.

Metasedimentary xenoliths similar to the pelitic to
psammitic country rocks are common, and amphibolite
inclusions occur locally. Folding defined by "ghost
layering may indicate a more complex structural history
than other foliated granitoids. However, this layering

Plate 3.5. Features of the Pitre Lake Granite. (a) Part of a concordant metasedimentary inclusion (centre) within the granite, which is the white material to left and right. (b) Complexly folded "ghost" layering, possibly inherited from the metasedimentary protolith.

Plate 3.6. Features of the Manak Island Granitoid. (a) and (b) Typical stained slabs of weakly foliated, leucocratic monzogranite. Foliation is not obvious in slabs, but is easily recognized on outcrop surfaces (no photo available).

could be an inherited feature if the granite was derived by
anatexis of its host rocks, which show similarly intricate
folding in nearby outcrops. No geochronological data are
available from the unit.

3.1.6 Manak Island Granitoid

This unit is located near Adlavik Bay (Figure 3.1),
and was previously grouped with the Cape Strawberry Granite
by Doherty (1980) and Gower et al.(1982). It is lithologically
distinct from the latter in all respects and has a
N-trending foliation. It consists of white to grey,
foliated granodiorite and monzogranite (Table 3.1; Plate
3.6). The unit resembles the more homogeneous variants of
the Brumwater Granite (see above), but is generally free of
xenoliths and ghost layering.

The unit forms a narrow zone between gabbro and
diorite of the Adlavik Intrusive Suite (see Chapter 5) and
adjacent monzonite and quartz monzonite of the Numok
Intrusive Suite (see Chapter 4). These surrounding units
are massive and undeformed, and the Manak Island unit
probably represents a screen between younger intrusions. It
is intruded by gabbro and diorite of the Adlavik Suite on
the adjacent mainland, but contacts with the Numok Suite
and the Upper Aillik Group at the southern end of Manak
Island have not been observed.

In thin section, the unit is variably recrystallized
to a polygonal mosaic, although scattered microcline and
'locally) zoned plagioclase phenocrysts are preserved. It
contains only minor amounts of sphene, apatite, zircon and
allanite.

No geochronological data are available from the unit,
but undeformed rocks of the adjacent Numok Suite have given
a U-Pb zircon age of 1801 ± 2 Ma. (Krogh et al., in

prep.). If differences in deformation state indicate
differences in age, this provides a lower limit for the age
of the Manak Island Granitoid.

3.1.7 Deus Cape Granitoid

This unit occurs in the extreme east of the study
area, adjacent to the Cape Harrison Metamorphic Suite
(Gower, 1981). It has been visited only in a few localities
during this project. The unit consists of coarse grained,
pink to grey, foliated, K-feldspar megacrystic to seriate
granodiorite (Table 3.1; details partly from Gower, 1981).

Contact relations are unknown, but the unit displays a
single NNE-trending foliation, and contrasts with the
adjacent polydeformed migmatitic rocks of the Cape Harrison
Suite (Gower, 1981). This contrast suggests that it
occupies a time slot between the Cape Harrison Metamorphic
Suite and undeformed Makkovikian plutonic rocks. Krogh et
al.(in prep) report a U-Pb zircon age of 1837 +6/-4 Ma from
this unit, which provides a minimum age fr - the Cape
Harrison Metamorphic Suite, which is the only candidate for
"basement" in the east of the area.

3.1.8 Island Harbour Bay Intrusive Suite

The Island Harbour Bay Intrusive Suite (Ryan et al.,
1983) lies outside the study area, but, as the largest
single Makkovikian plutonic body, merits some discussion.
The following outline is taken from Ermanovics et
al.(1982), Ryan et al.(1983) and I.Ermanovics (pers. comm.,
1988).

The suite includes a wide variety of rock types that
display complex field relationships. Ryan et al. (1983)
divided it into a grey tonalite to granodiorite, and a

homogeneous pink granite. The former is more abundant and forms the outer part of the intrusion; it is compositionally varied, inclusion-rich and polyphase. Ryan et al.(1983) distinguished diorite, quartz diorite, K-feldspar megacrystic granodiorite, and leucocratic granite, all of which show mutually intrusive relationships suggesting synchronous emplacement. The central granite unit lacks this complexity, and is commonly inclusion-free. It consists of pink to grey, feldspar porphyritic, locally megacrystic, biotite granite, locally containing interstitial fluorite. All of the above phases are intruded by pegmatite and aplite dykes.

The contact between outermost tonalite-granodiorite and Archean gneisses is described by Ryan et al.(1983) as a complex lit-par-lit migmatite zone, where foliations in the granitoid rocks are parallel to those in the gneisses. Early foliated granitoid dykes are cut by later undeformed phases, indicating syn- to post-tectonic emplacement. Foliations in the outer parts of the intrusion are locally cataclastic to mylonitic, and have concentric structural trends (Ryan et al., 1983). Rafts of Archean gneiss within this marginal zone display the strong "straightened" layering associated with early Makkovikian deformation (Ryan and Kay, 1982). The central portion of the body, in particular the granite unit, is massive to weakly foliated, and appears post-tectonic.

The Island Harbour Bay Intrusive Suite has been dated by a variety of methods. U-Pb zircon data from the dominant grey granodiorite (Loveridge et al, 1988) suggests an age of 1805 ± 5 Ma, similar to that of the Long Island Quartz Monzonite. This agrees well with Rb-Sr ages of 1805 ± 42 for the granite unit, and 1843 ± 90 Ma and 1794 ± 71 Ma for the tonalite-granodiorite unit (Grant et al., 1983). An

U-Pb zircon age of 1973 ± 15 Ma (Brooks, 1982) from the
tonalite unit is enigmatic. It may reflect inheritance, but
there is no evidence of inclusions in outcrop (B.Ryan
pers.comm., 1988), and no cores are reported from the
zircons. I.Ermanovics (pers. comm., 1988) considers the ca.
1800 Ma ages from the granite unit to be minimum ages only,
and states that the tonalitic rocks may be somewhat older.
As will be shown later, these tonalitic and trondhjemitic
compositions are not typical of the Makkovikian plutonic
assemblage in the study area.

3.2. DESCRIPTIVE GEOCHEMISTRY

Syn-tectonic Makkovikian plutonic rocks are represented by 186 samples; 121 of these are from "regional" samples collected on a 2 km grid spacing. The remainder are follow-up samples (mostly from the Kennedy Mountain Suite), and a small number of geological samples from all units (see Chapter 1 for explanation of sample populations). No samples were collected from the Island Harbour Bay Intrusive Suite; this is represented by 20 unpublished analyses supplied by B.Ryan (pers. comm., 1987).

3.2.1 General Geochemistry

Summary of Numerical Data

Average major, trace and partial CIPW normative compositions of syn-tectonic Makkovikian plutonic rocks are listed in Table 3.2. The Long Island Quartz Monzonite and tonalite to granodiorite of the Island Harbour Bay Intrusive Suite are silica-poor (63-65% SiO_2) compared to all other units (72-75% SiO_2). The four component units of the Kennedy Mountain Intrusive Suite have similar major and trace element compositions, as do the two geographic subdivisions of the Long Island Quartz Monzonite. The Melody Granite is broadly similar in composition to granites of the Kennedy Mountain Suite.

The remaining units show similar major element compositions but distinct trace element patterns. The Pitre Lake Granite is characterized by high Rb, F and Li relative

Table 3.2 . Average compositions of syn-tectonic Makkovikian plutonic rocks, subdivided by principal units.

UNIT	10.1		10.2		11.1		11.2		11.3		11.4		12.0	
nl	14		9		19		18		74		5		31	
n2	5				8		1		16		1		19	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	63.22	1.27	65.46	7.11	75.05	1.37	71.05	2.73	74.49	2.63	69.35	4.36	72.27	3.26
TiO2	0.88	0.06	0.69	0.34	0.28	0.24	0.42	0.15	0.23	0.13	0.51	0.22	0.35	0.21
Al2O3	15.79	0.23	15.84	2.42	12.31	0.48	13.71	0.82	12.32	1.01	14.45	1.55	13.50	1.10
Fe2O3	1.81	0.38	1.95	1.18	1.32	0.41	1.39	0.72	1.27	0.75	1.11	0.55	0.97	0.68
FeO	3.09	0.75	1.90	0.59	0.91	0.32	1.69	0.83	1.28	1.26	2.05	0.59	1.74	1.12
MnO	0.10	0.01	0.07	0.03	0.04	0.01	0.07	0.03	0.06	0.03	0.07	0.02	0.04	0.02
MgO	1.26	0.44	0.99	0.63	0.13	0.04	0.38	0.22	0.12	0.20	0.58	0.44	0.41	0.37
CaO	2.97	0.49	2.71	1.82	0.51	0.27	1.25	0.42	0.76	0.59	1.64	0.76	1.18	0.72
Na2O	4.28	0.26	4.28	0.31	4.61	1.16	4.30	0.92	4.34	1.13	3.99	0.43	3.80	0.76
K2O	4.77	0.51	4.50	0.31	4.14	1.82	4.84	1.15	4.19	1.56	5.25	0.49	4.59	0.99
P2O5	0.26	0.03	0.25	0.20	0.03	0.01	0.09	0.04	0.03	0.04	0.11	0.07	0.09	0.07
LOI	0.63	0.24	0.72	0.34	0.36	0.13	0.42	0.19	0.47	0.23	0.41	0.03	0.70	0.34
TOTAL	99.16		99.36		99.67		99.60		99.55		99.53		99.63	

(ppm)   Trace Elements

	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Li	23.6	4.6	19.9	15.8	15.2	10.2	25.6	15.5	10.4	7.0	27.2	8.1	18.1	13.5
F	873.2	214.7	809.8	499.5	661.5	544.7	936.1	315.2	1092.4	982.5	1145.8	484.2	613.7	481.2
Sc	9.6	1.7			1.5	0.6	0.8	0.0	1.1	0.7	4.4	0.0	2.9	1.6
V	76.3	19.2	49.0	31.8	12.7	6.2	21.4	8.6	12.3	10.5	45.6	21.5	24.3	17.7
Cr	5.6	3.6	3.2	1.4	4.3	4.0	3.6	1.9	5.3	4.0	3.2	2.2	3.7	3.5
Ni	2.7	1.9	1.2	0.4	1.4	1.1	1.3	0.7	1.3	1.3	1.6	0.9	1.7	1.5
Cu	9.3	3.9	5.2	2.0	2.5	0.8	5.2	4.3	3.6	3.9	6.2	4.1	7.3	15.1
Zn	74.0	8.8	61.8	17.9	65.8	29.7	73.7	24.7	87.3	61.8	60.6	19.2	45.0	27.9
Ga	18.4	1.2	14.4	4.4	16.5	7.1	14.5	5.7	17.3	7.7	18	2.0	18.3	2.2
Rb	127.9	24.4	118.0	29.2	129.7	62.1	163.0	49.3	127.9	67.4	185	42.0	122.0	36.0
Sr	327.2	40.5	348.8	274.2	31.8	9.4	103.9	55.2	51.6	78.5	137.2	86.1	106.8	89.9
Y	36.5	2.0	32.3	7.0	52.5	14.2	55.1	15.5	82.8	31.3	45.8	9.4	45.2	17.8
Zr	227.9	66.6	250.1	107.2	409.5	126.5	356.7	119.6	401.4	156.2	237.6	54.2	361.9	162.9
Nb	14.1	1.1	13.2	3.7	19.9	4.1	23.9	6.4	32.0	15.1	19.6	5.0	20.6	5.6
Mo	4.3	0.5	5.4	3.2	3.4	2.3	4.4	2.1	3.4	1.5	4.6	1.1	3.4	1.0
Sn	1.0	0.0			3.5	2.0	7.0	0.0	3.4	2.9	5	0.0	4.4	3.7
Cs	1.3	1.2			0.7	0.5	0.5	0.0	0.6	0.4	0.5	0.0	2.2	1.4
Ba	1424.3	120.6	1243.6	449.1	152.6	77.4	717.6	315.9	390.0	439.9	846	390.9	827.6	481.8
La	53.6	4.9	44.9	16.4	62.8	28.4	73.1	22.7	85.0	39.1	57.2	9.7	85.2	38.2
Ce	103.0	6.2	89.3	26.9	130.9	52.7	143.1	40.3	177.2	73.2	117.2	18.8	171.4	66.8
Sm	9.2	0.8			10.5	2.0	13.0	0.0	13.7	3.8	11	0.0	13.8	5.0
Yb	2.5	0.0			4.2	2.4	10.0	0.0	8.9	3.0	7	0.0	5.2	2.5
Hf	8.0	1.2			12.8	3.5	12.0	0.0	12.2	3.5	12	0.0	10.8	4.1
Pb	15.5	3.8	18.6	4.3	17.7	6.6	24.9	4.5	18.1	11.9	22.6	2.3	14.1	7.5
Th	9.5	2.7	8.1	9.6	10.7	7.7	19.2	6.8	15.9	10.3	23.8	12.0	12.1	6.1
U	4.9	0.8	3.3	1.0	3.7	2.5	6.3	2.9	4.5	2.9	7.16	2.8	3.7	2.0

(Wt%)   Partial CIPW norms

	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Q	12.07	1.68	17.31	11.38	31.61	2.89	24.31	5.12	31.64	5.41	21.40	8.76	29.06	5.53
C	0.00	0.00	0.09	0.15	0.03	0.07	0.01	0.03	0.01	0.07	0.02	0.05	0.38	0.46
Or	28.59	3.02	26.91	1.83	24.63	10.87	28.84	6.85	24.96	9.31	31.32	3.06	27.43	5.87
Ab	36.73	2.08	35.85	1.28	39.17	9.84	36.67	7.84	36.86	9.30	34.09	3.77	32.48	6.48
An	9.97	1.50	10.61	5.54	0.66	0.47	3.82	1.88	1.84	1.97	5.98	2.69	5.24	3.02
Di	3.05	1.23	1.34	2.07	0.84	0.63	1.53	1.07	1.08	1.21	1.42	0.99	0.20	0.45
Hy	4.62	1.78	2.31	1.72	0.26	0.39	1.81	1.51	0.94	2.08	2.89	1.12	2.94	2.30
Ol	0.00	0.00	0.39	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mt	2.67	0.56	2.63	1.35	1.64	0.57	1.69	0.90	1.57	0.80	1.62	0.81	1.25	0.74
Il	1.69	0.13	1.34	0.66	0.53	0.45	0.77	0.31	0.44	0.24	0.98	0.42	0.67	0.41

KEY TO UNITS (KMIS - Kennedy Mountain Intrusive Suite)
10.1 -- Long Island Quartz Monzonite (main body)   10.2 -- Long Island Quartz Monzonite (other)
11.1 -- (KMIS) Kennedy Mountain Granite   11.2 -- (KMIS) Narrows Granite
11.3 -- (KMIS) Cross Lake Granite   11.4 -- (KMIS) other units
12.0 -- Melody Granite
nl -- number of analyses for all elements except those listed below.
n2 -- number of analyses for Sc, Sn, Cs, Sm, Yb and Hf.

Table 3.2 (continued)

UNIT	13.0		14.0		15.0		16.0		18.1		18.2	
n1	4		4		6		2		15		5	
n2												
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	72.73	1.26	76.18	0.38	70.13	0.69	75.68	4.42	66.13	6.51	73.38	1.52
TiO2	0.16	0.09	0.05	0.02	0.31	0.03	0.17	0.10	0.52	0.36	0.20	0.05
Al2O3	14.66	0.44	12.87	0.23	15.83	0.40	12.64	1.94	16.44	1.40	14.52	0.73
Fe2O3	0.64	0.44	0.36	0.24	1.06	0.26	1.03	0.28	1.19	0.97	0.30	0.15
FeO	0.66	0.29	0.43	0.25	0.90	0.19	0.54	0.20	2.26	1.46	0.96	0.11
MnO	0.03	0.01	0.03	0.01	0.04	0.01	0.04	0.01	0.05	0.04	0.03	0.01
MgO	0.65	0.27	0.02	0.01	0.54	0.03	0.31	0.23	1.41	1.36	0.38	0.23
CaO	0.99	0.03	0.47	0.17	1.78	0.21	0.63	0.11	3.48	1.94	0.97	0.61
Na2O	5.06	0.93	4.31	0.26	4.89	0.19	3.36	1.08	4.61	0.50	4.03	0.28
K2O	3.34	1.46	4.32	0.24	3.93	0.14	4.79	0.08	2.52	1.08	4.08	1.16
P2O5	0.06	0.02	0.02	0.01	0.12	0.01	0.03	0.03	0.19	0.19	0.04	0.01
LOI	0.93	0.29	0.62	0.04	0.42	0.16	0.67	0.11	0.98	0.42	0.78	0.02
TOTAL	99.91		99.66		99.95		99.86		99.78		99.67	
(ppm)												
Li	11.5	1.7	162.5	98.0	22.5	6.1	12.0	0.0				
P	187.5	68.4	2660.5	746.6	411.3	133.9	230.0	14.1				
Sc												
V	21.5	8.5	13.0	2.4	29.0	4.9	14.0	7.1	55.7	48.4	28.0	24.1
Cr	7.5	5.7	4.5	1.7	2.5	0.8	1.0	0.0	15.0	37.5	5.0	0.0
Ni	3.0	2.7	1.5	0.6	1.5	0.5	1.5	0.7				
Cu	3.5	1.3	2.0	1.2	4.5	1.2	8.5	5.0				
Zn	29.3	3.9	61.3	23.9	43.2	10.2	54.0	4.2				
Ga	6.8	1.7	16.5	7.2	13.2	2.9	16.5	2.1	21.5	2.6	19.6	3.4
Rb	96.5	41.0	411.5	163.4	79.3	24.9	164.5	37.5	70.7	24.8	257.0	166.0
Sr	273.5	47.5	7.8	2.2	596.3	75.3	48.0	25.5	540.2	290.5	173.0	177.8
Y	5.8	1.7	125.0	32.8	8.5	1.2	41.5	21.9	10.9	7.1	45.0	51.3
Zr	88.0	38.0	114.3	23.1	162.0	26.1	256.0	53.7	163.3	76.4	110.0	19.1
Nb	2.0	0.0	36.5	11.6	5.0	1.3	23.5	0.7	8.3	5.7	20.8	18.6
Mo	2.0	0.0	2.0	0.0	2.0	0.9	3.5	0.7				
Sn												
Cs												
Ba	912.5	446.6	42.0	38.2	1560.0	174.4	209.5	171.8	774.4	330.4	674.0	592.0
La	13.8	4.6	12.3	4.3	26.0	5.3	49.0	2.8	29.2	11.0	22.6	5.2
Ce	19.0	11.6	32.5	9.9	46.0	8.7	103.0	5.7	50.3	17.0	36.4	8.6
Sm												
Yb												
Hf												
Pb	12.5	7.9	61.5	1.3	11.3	2.8	5	14.8				
Th	1.8	1.0	23.3	18.2	4.8	2.9		7.8	6.3	4.1	24.0	19.2
U	1.7	0.5	8.6	8.2	1.8	0.4	..8	2.8				
(Wt%)												
Q	27.56	2.39	33.68	0.70	22.02	1.87	36.33	11.44	19.78	8.28	31.50	5.77
C	0.98	0.48	0.30	0.23	0.40	0.24	0.86	0.05	0.51	0.46	1.80	1.73
Or	19.88	8.64	25.77	1.40	23.32	0.82	28.50	0.57	15.08	6.46	24.39	6.87
Ab	43.23	8.08	36.77	2.22	41.55	1.66	28.67	9.27	39.48	4.30	34.42	2.37
An	4.84	0.26	2.24	0.90	8.59	1.06	2.99	0.40	15.51	7.54	4.75	3.13
Di	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84	1.89	0.00	0.00
Hy	2.12	0.72	0.60	0.40	1.78	0.43	0.77	0.59	5.52	4.53	2.22	0.45
Ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.26	0.00	0.00
Mt	0.94	0.64	0.38	0.14	1.40	0.32	1.37	0.38	1.75	1.43	0.44	0.21
Il	0.31	0.17	0.10	0.03	0.58	0.07	0.33	0.19	0.99	0.70	0.38	0.11

KEY TO UNITS (IHBIS -- Island Harbour Bay Intrusive Suite)
13.0 -- Brunwater Granite   14.0 -- Pitre Lake Granite
15.0 -- Nanak Island Granitoid   16.0 -- Deus Cape Granitoid
18.1 -- IHBIS (tonalite-granodiorite)   18.2 -- IHBIS (granite)

n1 -- number of analyses for all elements except those listed below.
n2 -- number of analyses for Sc, Sn, Cs, Sm, Yb and Hf.

to all other units. The Manak Island and Brumwater units
are similar, but the former shows higher Ba and Sr,
consistent with a lower SiO_2 content. These units, and
the granites from the Island Harbour Bay Suite, are
distinguished by low Zr, Y, Nb, La and Ce compared to the
Long Island and Kennedy Mountain units. The mean
composition for the Deus Cape Granitoid (2 samples only) is
probably not representative of the unit.

Abundance and Distribution of Rock Types

IUGS rock types were calculated from normative data
(after Streckeisen and LeMaitre, 1979, see Chapter 1) for
regional and geological sample populations. This provides
an unbiased method of comparing compositional spectra.
Relative abundances (Figure 3.2) indicate that this
association is dominated by granite (s.s.) and
alkali-feldspar granite, with lesser amounts of quartz
monzonite, quartz syenite and monzogranite.

The Long Island unit contains most of the quartz
monzonite to monzogranite, whereas the Kennedy Mountain
Intrusive Suite and Melody Granite are dominated by granite
and alkali-feldspar granite. Minor units (not figured) are
also dominated by granite (s.s), except for the Manak
Island unit, which is a monzogranite. No analysis has been
attempted for the Island Harbour Bay Suite (data are
insufficient), but a major-element study by Ermanovics
(pers. comm., 1988) suggests a wide range of compositions,
including significant tonalite - trondhjemite (see also
Ryan et al., 1983)
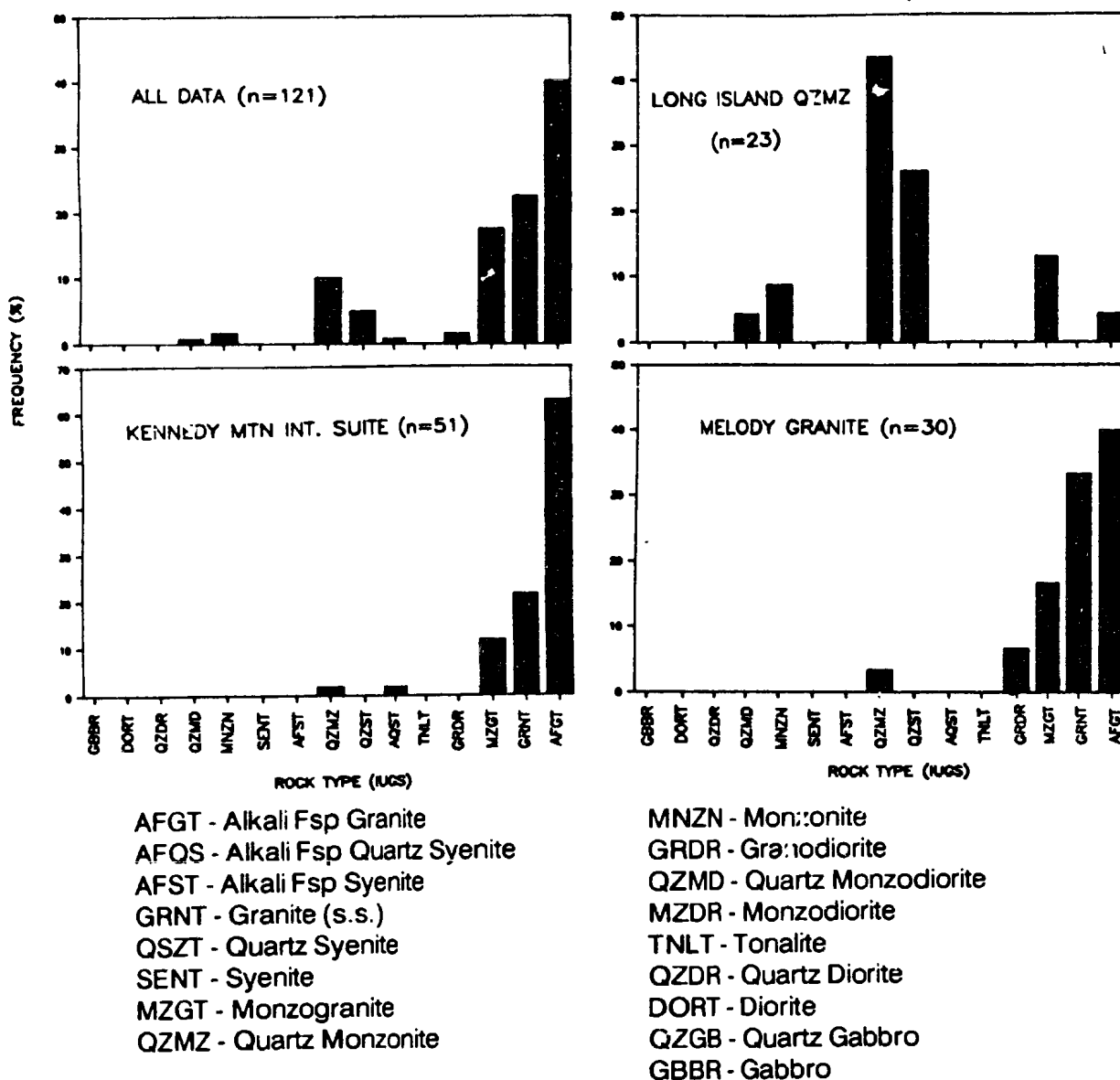
Figure 3.2 . Relative abundance of IUGS rock types calculated from normative mineralogy using the method of Streckeisen and LeMaitre (1979). Note that this is based on Barth mesonorms, not the CIPW norms listed in Table 3.2. Abundances are not given for minor units, due to small numbers of samples.

3.2.2 Geochemical Trends and Contrasts

Syn-tectonic Makkovikian plutonic rocks are subdivided into three groups (A,B and C) represented by separate columns of diagrams in Figures 3.3 to 3.11. This method is intended to reduce "clutter", and no genetic links are implied by these groupings.

Major Element Patterns

Major element variations show expected patterns. All elements (except Na_2O and K_2O) are negatively correlated with SiO_2 (e.g. TiO_2 and FeOt; Figure 3.3), and do not discriminate between units. Within the Kennedy Mountain Suite, the Kennedy Mountain and Cross Lake Granites show the most evolved, high-SiO_2 compositions. The Melody Granite coincides with the Kennedy Mountain Intrusive Suite. Na_2O (Figure 3.3) and K_2O (not shown) display little systematic variation and exhibit considerable scatter above 70% SiO_2 in the Kennedy Mountain Suite.

Agpaitic Index [K+N/A] and Alumina Index [A/C+N+K] (see Chapter 1 for details) distributions provide better unit discrimination. K+N/A defines two subparallel trends (Figure 3.3; dotted line defines boundary). The "upper trend" includes the Long Island Quartz Monzonite and Kennedy Mountain Intrusive Suite, and terminates in a dense grouping at 75-78% SiO_2 that includes some peralkaline compositions (K+N/A > 1.0). The "lower trend" is defined by the Melody, Manak Island, Brumwater and Pitre Lake units, and by parts of the Island Harbour Bay Suite; this terminates at K+N/A values below 0.94. A/C+N+K values (Figure 3.3) indicate that the "lower trend" units are
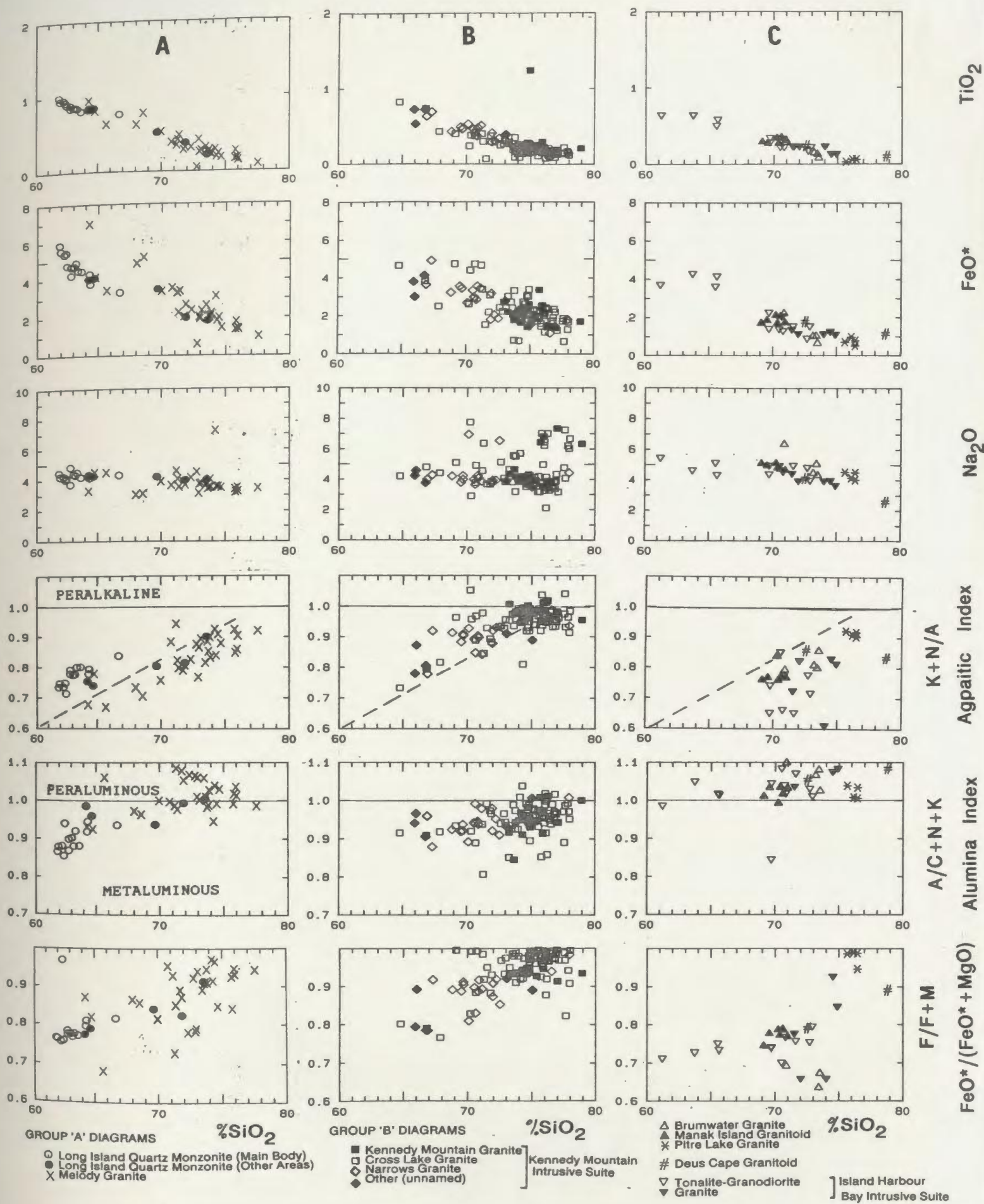
Figure 3.3 . Variation of selected major elements and derived ratios in syn-tectonic Makkovikian plutonic units. See text for discussion.

largely peraluminous (A/C+N+K > 1.0), whereas the "upper trend" is metaluminous. These two contrasting groups are referred to below as the metaluminous-peralkaline and peraluminous associations respectively. F/F+M ratios (Figure 3.3) indicate that the former association shows Fe-enrichment relative to most members of the peraluminous association. Note also that the latter are not "S-type" granites in the sense of Chappell and White (1974), which are defined as having A/C+N+K $\geq$ 1.1.

Ternary AFM [(Na$_2$O+K$_2$O) - FeOt - MgO] and CNK [Na$_2$O - K$_2$O - CaO] projections (Figure 3.4) show a superficial "calc-alkaline" trend for all units. Linear regression of all data suggests that the alkali-lime index (i.e. SiO$_2$ value at which Na$_2$O+K$_2$O = CaO) is ca. 57%; in the original definition of such terms (Peacock, 1931) this association is alkali-calcic. The Q-B-F ternary projection of Debon and LeFort (Figure 3.4) suggests an affinity to subalkaline or alkaline- oversaturated (their terminology), rather than calc-alkaline suites.

The CNK projection (Figure 3.4) indicates alkali disturbance (mostly Na-enrichment) in granites of the Kennedy Mountain Intrusive Suite. Variation of N/N+K [Na$_2$O/(Na$_2$O+K$_2$O] ratios and total alkali content (Figure 3.5; c.f. Hughes, 1973) indicate that disturbed compositions lie outside the normal igneous spectrum, suggesting post-crystallization alteration (see later discussion). Total alkali content is unaffected by alkali disturbance (Figure 3.5).

Normative Compositions

All units of the peraluminous association are corundum-normative (Table 3.2). Variations in the Q - Ab - An - Or quaternary system (Figure 3.6) indicate that the
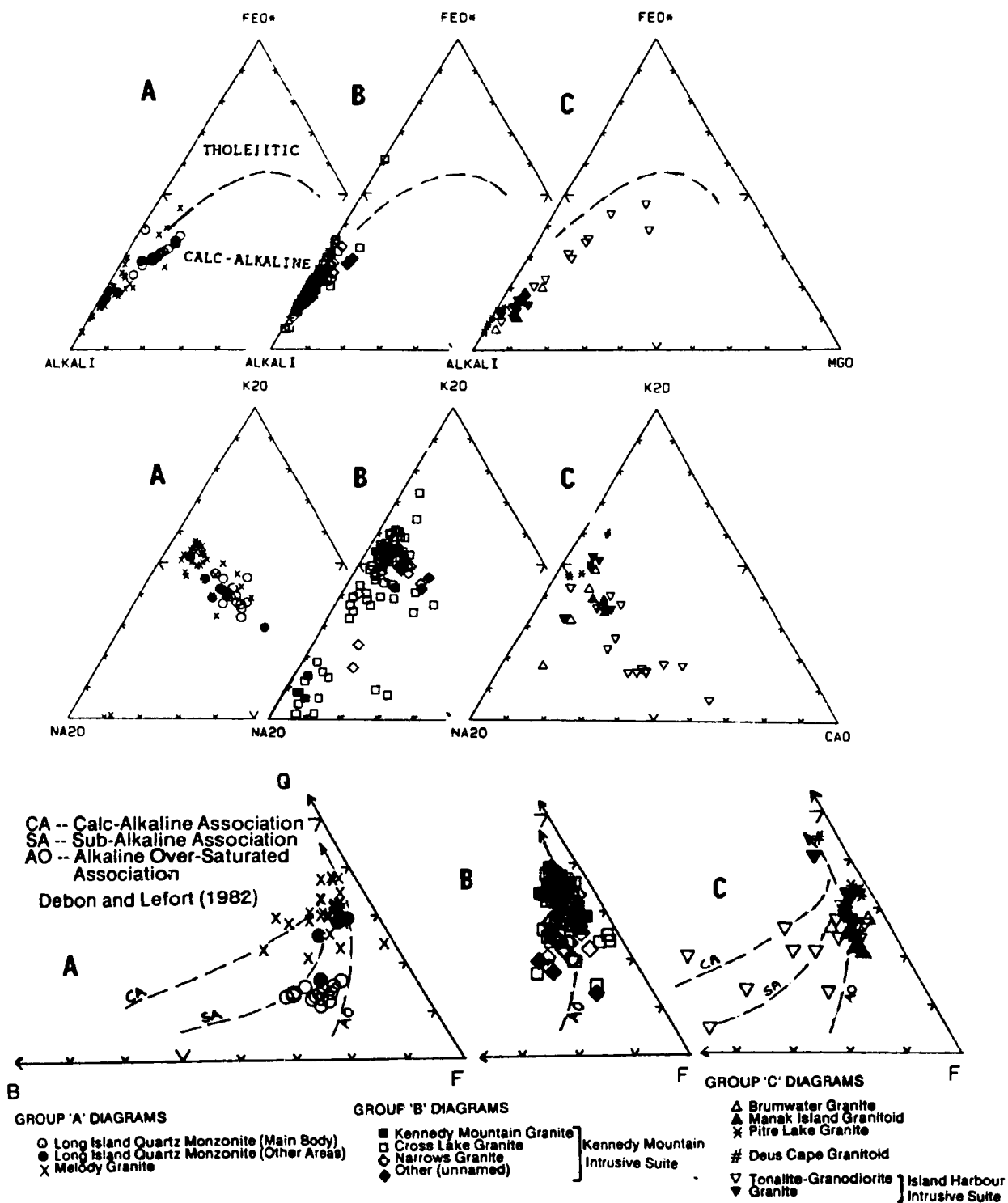
Figure 3.4 . AFM, CNK and QBF ternary projections for syn-tectonic Makkovikian plutonic units. See text for discussion.
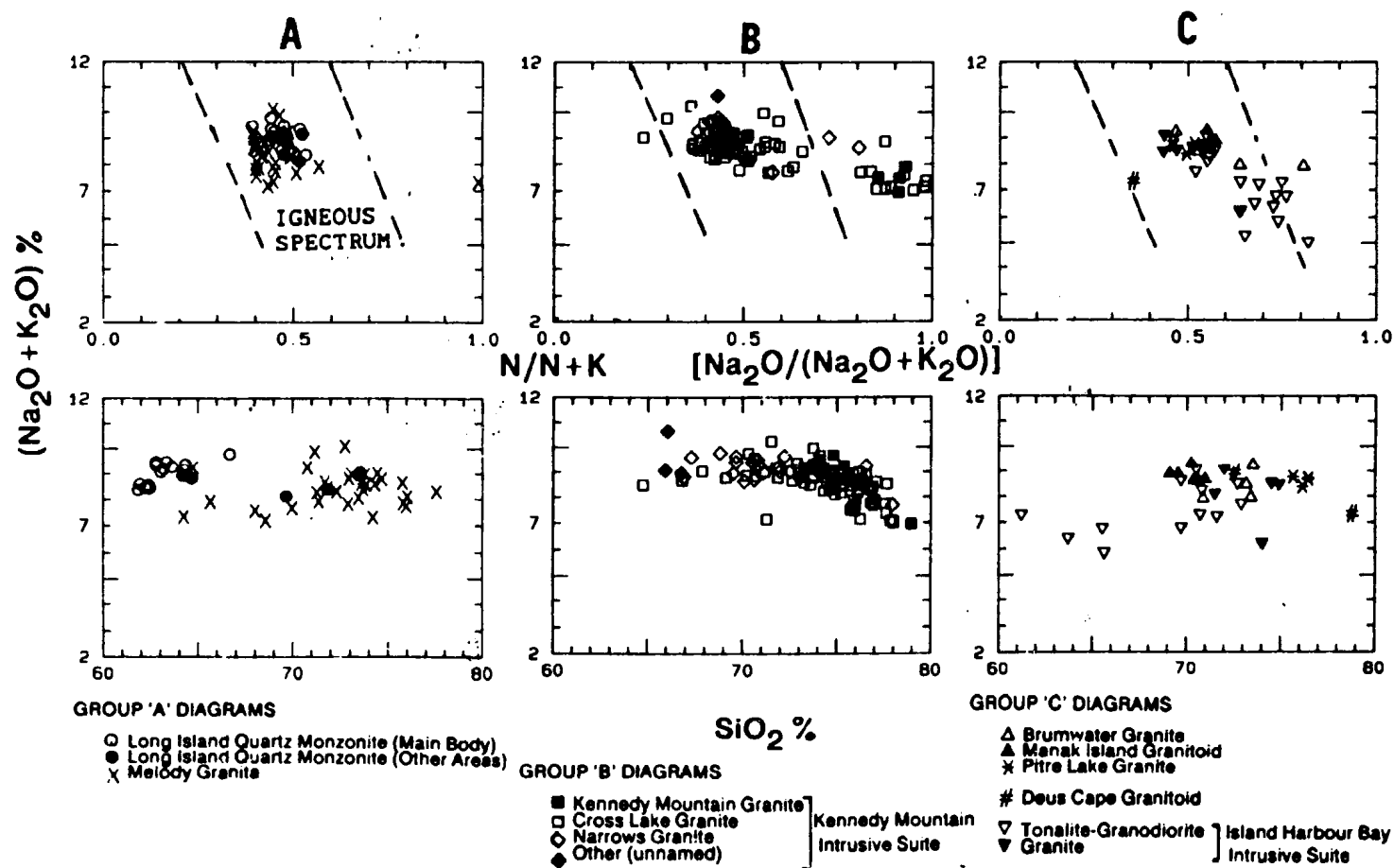
Figure 3.5. Distribution of alkali elements and N/N+K ratios in relation
to the igneous spectrum (after Hughes, 1973). The SiO_2-total alkali
plot demonstrates the constancy of (Na_2O+K_2O) in altered and
unaltered variants.

Kennedy Mountain Suite and Melody Granite contain less than
10% normative anorthite, and lie close to the ternary
eutectic minima for bulk compositions with appropriate
Ab/An ratios (James and Hamilton, 1969). Granite units of
the peraluminous association are displaced from this
location towards the Ab corner, but still lie in the
general area of ternary minima for the granite system. The
Long Island Quartz Monzonite lies close to the plagioclase
- K-feldspar cotectic lines of James and Hamilton (1969)
for An-poor compositions. Note the anomalously calcic
composition of tonalites and granodiorites from the Island
Harbour Bay Suite compared to all other units.

Trace Element Patterns

Trace element patterns are discussed in terms of
element groupings defined in Chapter 1, adapted from
Saunders et al. (1979).

Octahedrally Co-ordinated Cation (OCC) Elements :
These "compatible" trace elements show strong inverse
correlation with SiO_2 (e.g. V, Figure 3.7). Only the Long
Island Quartz Monzonite has significant enrichment,
consistent with its lower SiO_2 content compared to other
units.

Low Field Strength (LFS) Elements : Incompatible
(e.g. Rb, Th, Cs) and compatible (e.g. Ba, Sr) LFS elements
show antithetic behaviour (Figure 3.7). Ba and Sr are
inversely correlated with SiO_2, particularly above 70%
SiO_2. The Manak Island and Brumwater units, and parts of
the Island Harbour Bay Suite, are characterized by high Ba
and Sr for their SiO_2 content. Extreme depletion in both
elements is shown by high-silica rocks of the Kennedy
Mountain Suite, and also by the Pitre Lake Granite.
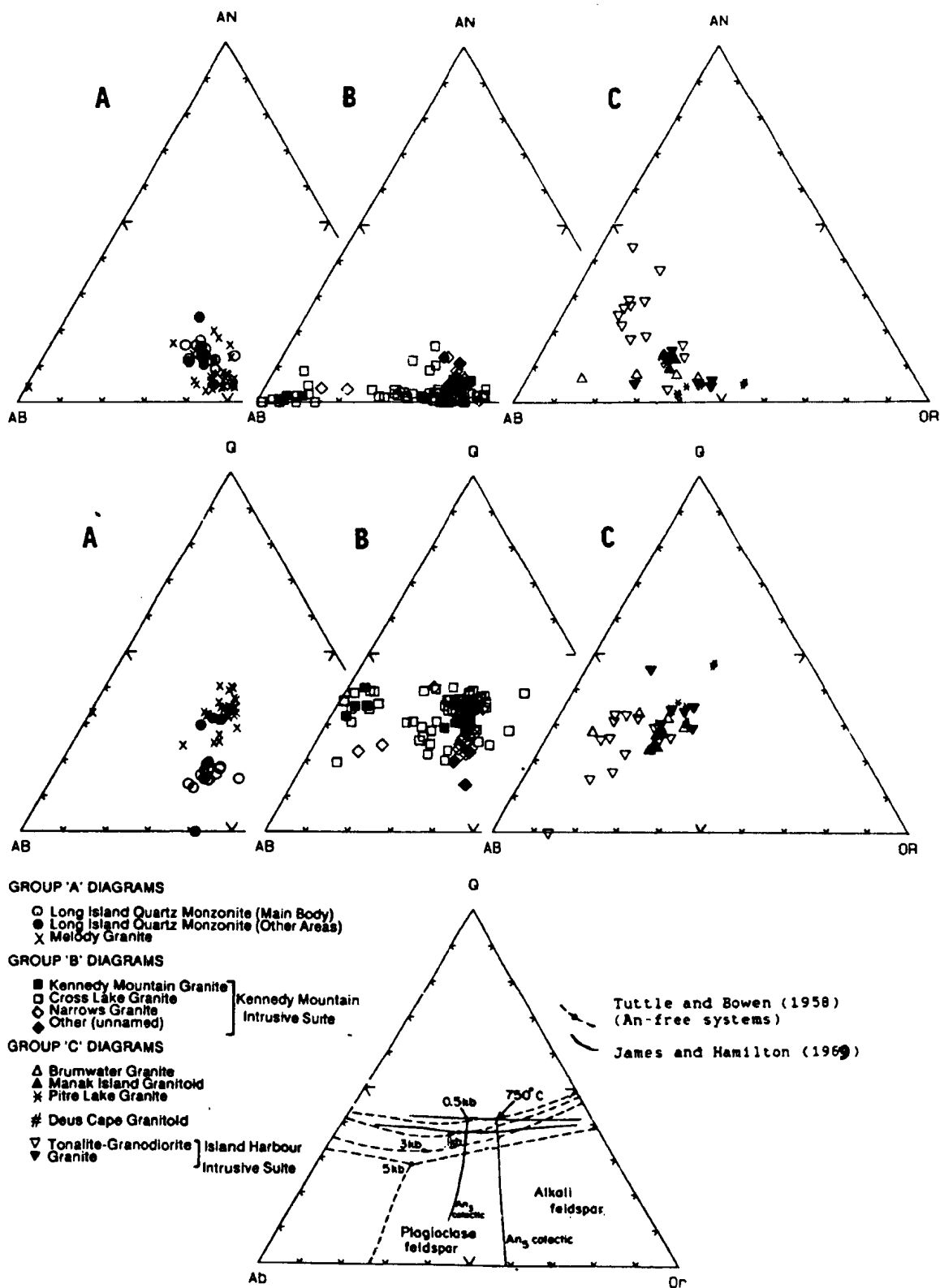
Figure 3.6. Variation of syn-tectonic Makkovikian plutonic units in the quartz – albite – anorthite – orthoclase quaternary system. All norms are CIPW. See text for discussion.

Rb and Th (Figure 3.7) lack good correlation with
SiO_2. Weak positive trends exist below 70% SiO_2, but
data are scattered in high-silica granites, particularly in
the Kennedy Mountain Intrusive Suite. Partial data for Cs
(Figure 3.7) suggest that the Melody Granite is enriched
relative to all other units for which data are available.
The Pitre Lake granite has very high Rb; 2 samples have
over 400 ppm Rb and are excluded from the figure. Some of
the granites from the Island Harbour Bay Suite have Rb and
Th contents similar to the Pitre Lake granite.

High Field Strength (HFS) Elements : Zr (Figure 3.8)
and also Nb and Hf (not figured) are enriched in the
Kennedy Mountain Intrusive Suite relative to most other
units, and are disorganized above 70% SiO_2. The Melody
Granite is partly coincident with the Kennedy Mountain
Suite for these elements, but shows generally lower Zr.
Most other members of the peraluminous association are
depleted in Zr. The Pitre Lake shows an unusual combination
of Nb enrichment and Zr depletion, which is also shown by
some granites of the Island Harbour Bay Suite.

Rare Earth Elements (REE) : Variation patterns for
Ce and Y (Figure 3.8) resemble those for Zr and Nb
respectively. The Island Harbour Bay Suite , Manak Island,
and Brumwater units are characterized by low REE abundances
relative to the Kennedy Mountain Suite. The Pitre Lake
Granite shows Y enrichment and Ce depletion. Partial data
for Sm and La resemble Ce; partial data for Yb resemble Y.

Indeterminate Trace Elements : Li is strongly
enriched in the muscovite-bearing Pitre Lake Granite (two
samples contain over 150 ppm Li), but is low in most other
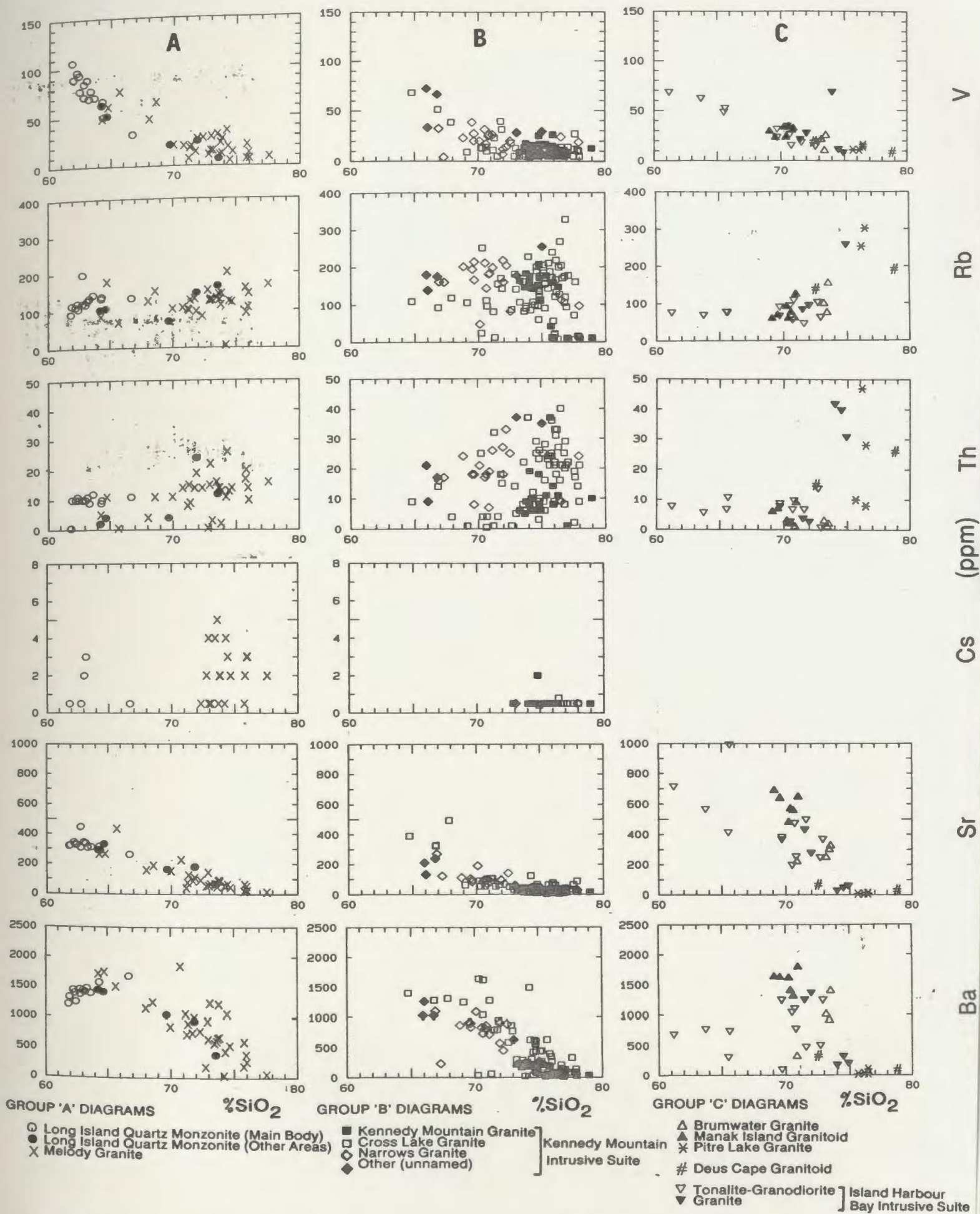
Figure 3.7. V, Rb, Th, Cs, Sr and Ba versus SiO$_2$ in syn-tectonic Makkovikian plutonic units. See text for discussion.
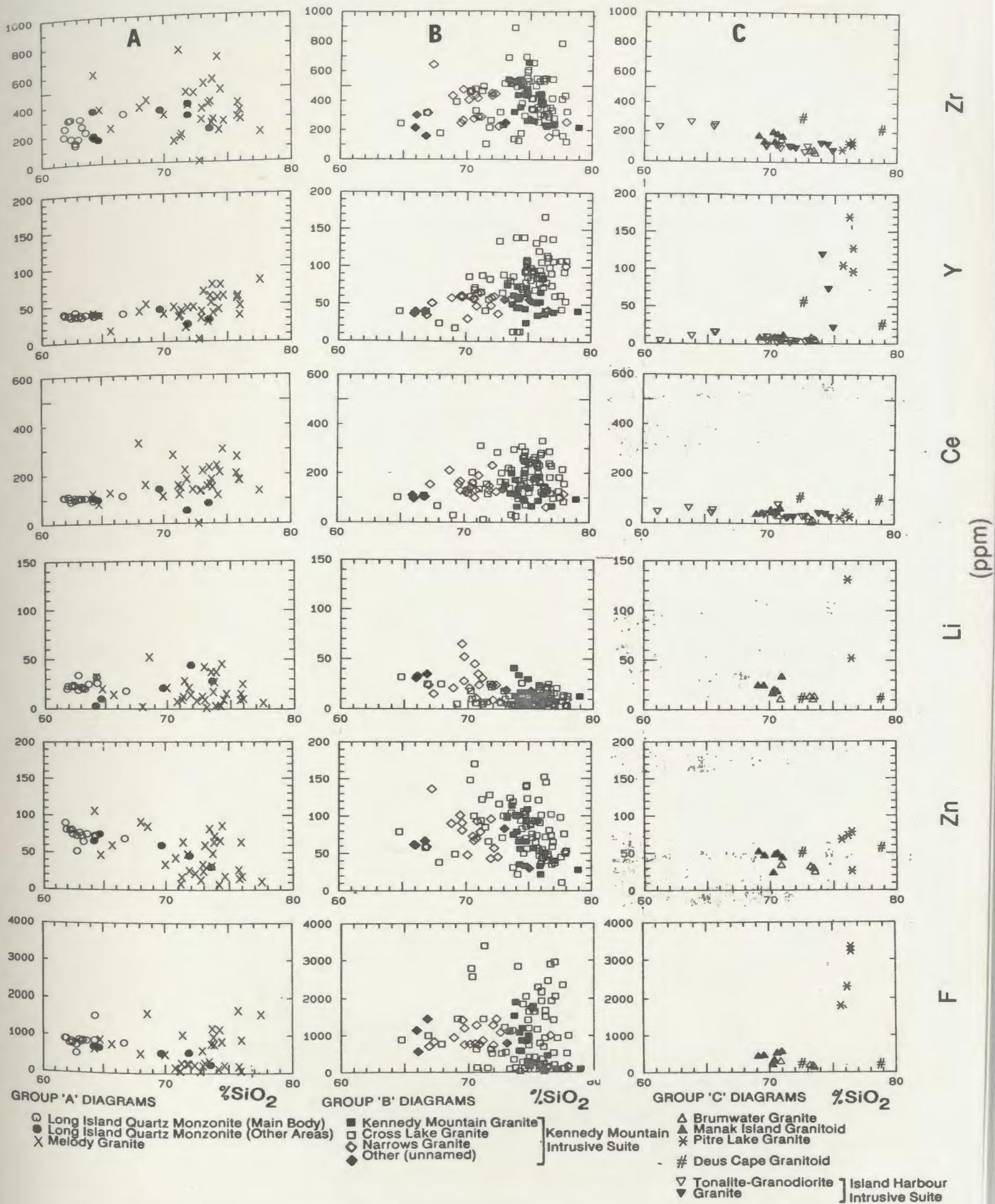
Figure 3.8 . Zr, Y, Ce, Li, Zn and F versus SiO$_2$ in syn-tectonic Makkovikian plutonic units. See text for discussion.

units. The Kennedy Mountain Intrusive Suite shows variable Zn and F enrichment at high SiO_2 contents, and is locally strongly F-enriched (up to 4000 ppm). Granitoids of the peraluminous association are low in F, except for the Pitre Lake Granite.

Trace Element Variation and Alkali Disturbance

Correlation between trace element behaviour and alkali disturbance in the Kennedy Mountain Suite was assessed by using N/N+K as the X-axis variable (Figure 3.9). For LFS trace elements (e.g. Rb, U, Ba and Sr, possibly also Li), disturbed Na-rich compositions show depletion, but there is little systematic variation of HFS elements, REE, Zn and F. This indicates that any metasomatic processes affected feldspars and micas, and had minimal effect on accessory or mafic phases. In conjunction with constant total alkali contents, it suggests cation-exchange as a possible mechanism (c.f. White and Martin, 1980). It also indicates that the enhanced levels of fluorine, HFS elements and REE that characterize the Kennedy Mountain Suite are primary features of the parent magmas, not a consequence of hydrothermal activity (see later discussion).

Trace Element Ratios

Trace element ratios provide a method of assessing fractionation history, as evolution paths resulting from fractional crystallization should define lines or smooth curves in log-log plots (e.g. McCarthy and Hasty, 1976). Reference paths for common silicates, using crystal-liquid partition coefficients from Arth (1976) and Hanson (1978) are illustrated in the key to figure 3.10.
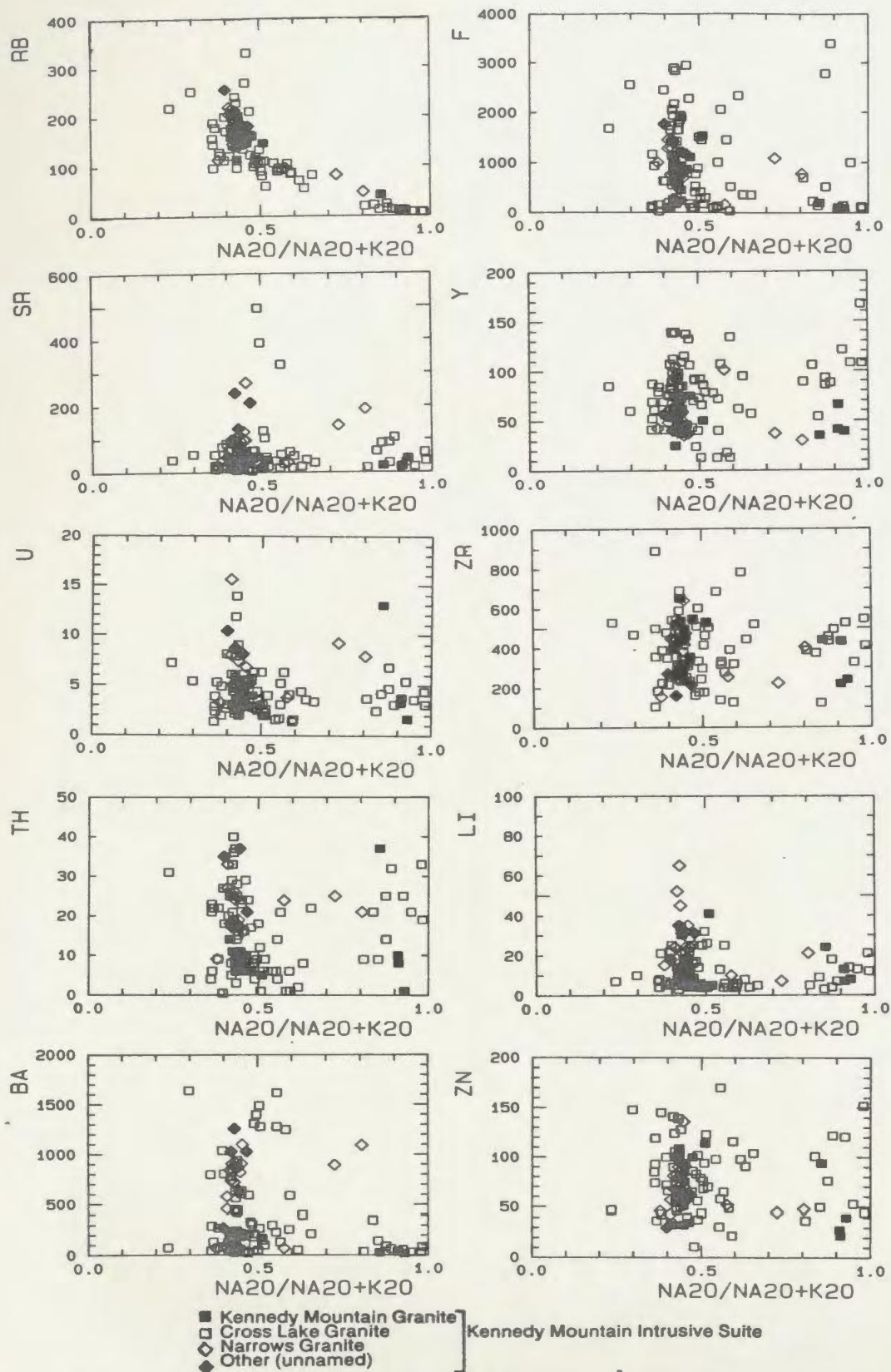
Figure 3.9 . Variation of selected trace elements against N/N+K [Na_2O / (Na_2O+K_2O)] in the Kennedy Mountain Intrusive Suite.

K/Rb ratios show minimal variation (Figure 3.10) from 500 to 200; only the Pitre Lake Granite, parts of the Island Harbour Bay Suite and a few granites from the Kennedy Mountain Suite show ratios below 200. The general trend is towards lower K/Rb with increasing SiO_2. The Kennedy Mountain Suite includes a disturbed population depleted in both K and Rb (note the different X-axis scale for the group B diagram).

Rb/Sr ratios vary widely (Figure 3.10). The Long Island unit, Kennedy Mountain Suite (note disturbed population) and Melody Granite have flat-lying trends suggesting moderate Rb enrichment, consistent with feldspar fractionation.

Ba/Sr ratios are broadly similar (1 - 30) for all units (Figure 3.10). The metaluminous-peralkaline association and Melody Granite have curvilinear trends indicating progressive Ba and Sr depletion, and increasing depletion of Ba relative to Sr. The remaining members of the peraluminous association show higher Ba and Sr, and define a shallower depletion trend. The steep, curved trends are consistent with significant effects from K-feldspar or biotite fractionation.

Variation in La_N/Y_N ratios (subscript indicates normalization to chondrite) indicates REE fractionation, as Y mimics the heavy rare-earth element (HREE) Yb. It also provides a fingerprint for effects caused by accessory phases (see key to Figure 3.10 for details). The metaluminous-peralkaline association is tightly clustered and positively correlated, with a range in La_N/Y_N from 20 to 80. A similar distribution is shown by the Melody Granite. La and Y are correlated weakly with SiO_2 (Figure 3.8; La is similar to Ce), but strong enrichment expected
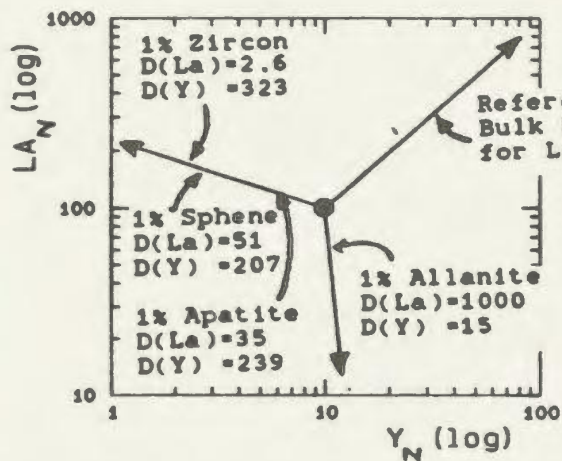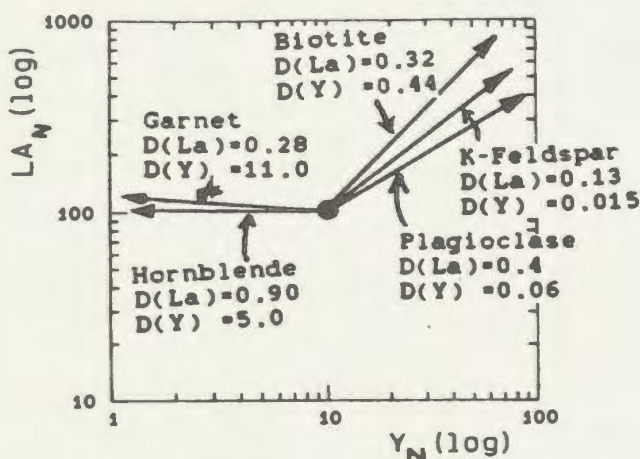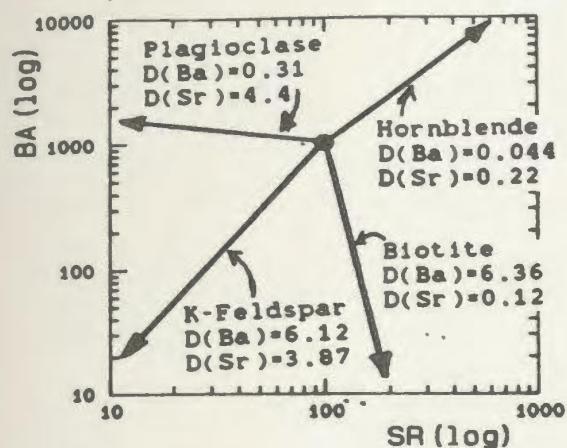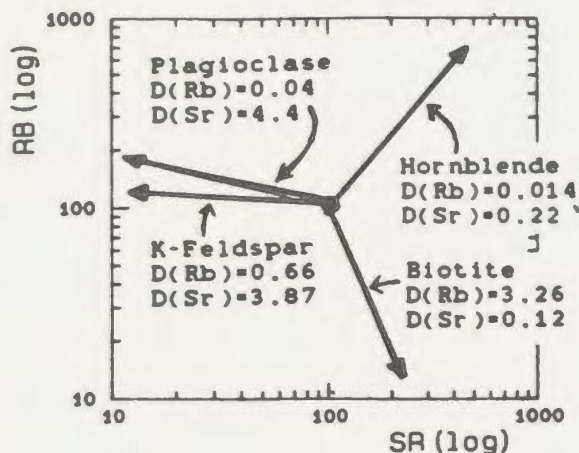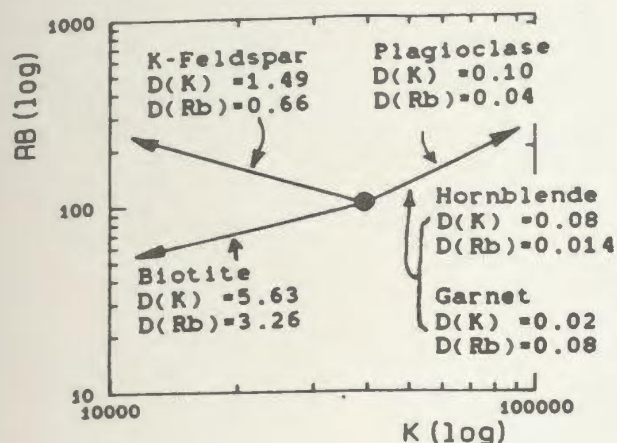
Idealized fractionation trends for Rayleigh fractionation (ï.e. perfect separation of crystals and liquid). The La_N/Y_N trends for accessory phases show the effects of only 1% of each phase upon a reference trend where bulk partition coefficients for the remaining 99% of the fractionate are 0.1 for both La and Y. The latter approximates a "normal" path for fractionation of common silicates. Partition coefficent data from compilations by Arth (1976) and Hanson (1978) for most minerals, and from Gromet and Silver (1983) for allanite and sphene.
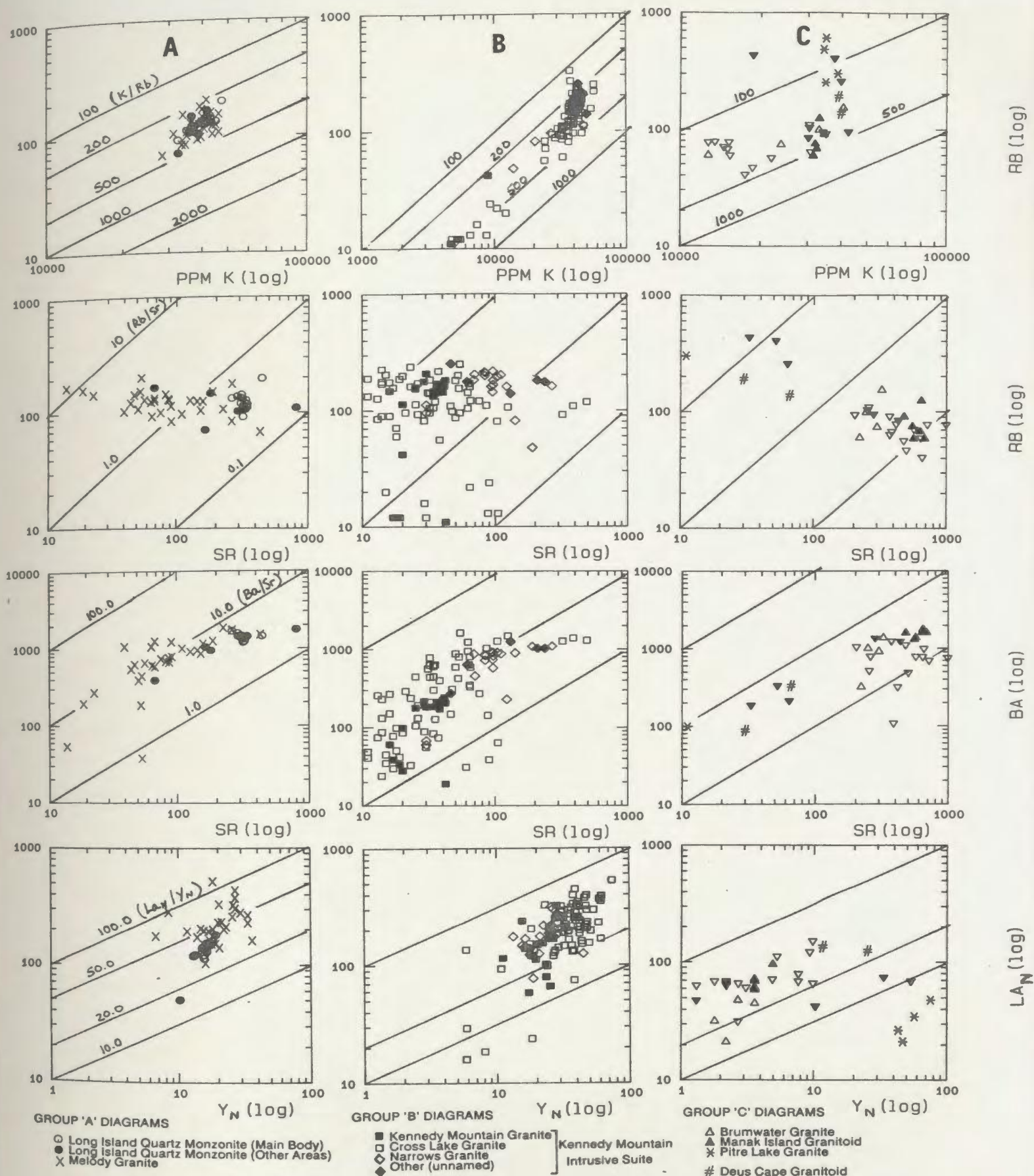
Figure 3.10 . Variation in the trace element ratios K/Rb, Rb/Sr, Ba/Sr and La$_N$/Y$_N$ in syn-tectonic Makkovikian plutonic units. See opposite for reference fractional crystallization trends.

from feldspar fractionation is not obvious. There is, however, no evidence for the Y depletion that should accompany significant fractionation of sphene, zircon or apatite, or La depletion caused by allanite or monazite.

Remaining granitoids of the peraluminous association show low La and Y, but greater variation of La_N/Y_N. Their trends are consistent with effects from "removal" of accessory phases; in the case of the Pitre Lake Granite, this must have been a LREE-rich phase such as allanite or monazite. As discussed subsequently (3.3), this may be a function of residual material, rather than fractional crystallization.

Rare-Earth Element (REE) Patterns

Representative samples have been analyzed for the full REE spectrum (Figure 3.11; data listed in Appendix B). The Kennedy Mountain Suite granites have fractionated LREE patterns (200-300 x chondrite), strong negative Eu anomalies, and HREE patterns that vary from flat to steep. Deepening of the Eu anomaly is associated with increasing HREE fractionation. The least fractionated patterns resemble the Long Island REE pattern. The Eu anomaly indicates plagioclase and/or K-feldspar fractionation (see also Figure 3.10); HREE fractionation is probably a function of sphene and zircon extraction in the most fractionated rocks. The Melody Granite REE pattern resembles typical Kennedy Mountain Suite examples.

REE patterns for the Manak Island and Brumwater Granitoids are remarkably similar; they are steep, and lack negative Eu anomalies. A similar profile is shown by the tonalite-granodiorite unit of the Island Harbour Bay Suite. The Pitre Lake Granite has an unusual flat REE pattern with a strong negative Eu anomaly.
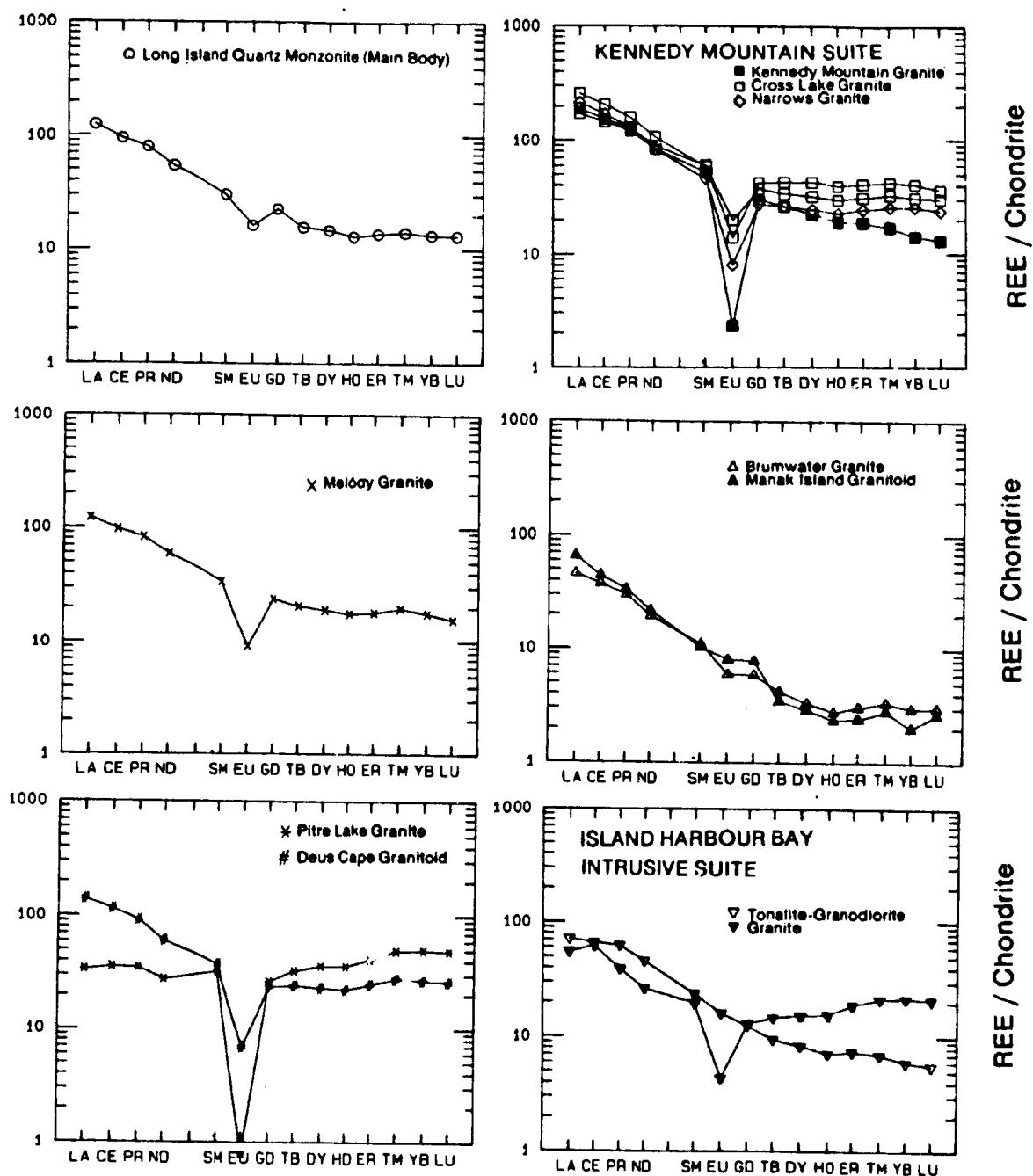
Figure 3.11 . Rare Earth element (REE) patterns for representative syn-Makkovikian plutonic rocks. Values are normalized to chondritic values (listed in Appendix C).

3.3 SUMMARY AND DISCUSSION

Geological and Petrographic Associations

Syn-tectonic Makkovikian plutonic rocks can be divided into two groups based on their field and petrographic characteristics.

The Long Island Quartz Monzonite, Kennedy Mountain Intrusive Suite and Melody Granite are regionally extensive, homogeneous units. They are xenolith-poor; inclusions, where present, commonly appear to be cognate, darker-coloured phases. There is no evidence of anatectic melting in their country rocks, suggesting that they were derived from well below the current level of exposure. The Long Island and Kennedy Mountain Suite units are both dominated by hornblende - biotite granitoids, with hornblende-poor leucocratic variants. Whatever the ultimate sources of these intrusions, they were not derived from their country rocks at the present level of exposure.

A totally different environment is represented by small foliated granitoid units of the Kaipokok Bay area (Brumwater and Pitre Lake Granites). These units are confined to specific units in the basement complex or Lower Aillik Group, and, although intrusive, have contacts that are regionally concordant to layering and/or stratigraphy. Both the Pitre Lake and Brumwater Granite locally appear gradational with surrounding rocks (Marten, 1977), and contain abundant metasedimentary and gneissic xenoliths respectively. There is evidence of migmatization in the country rocks, and Marten (1977) suggested that the Brumwater Granite was gradational with migmatitic Archean gneiss. The composition and setting of the Pitre Lake unit

suggests derivation by anatexis of local metasedimentary
rocks. Both units were apparently derived by melting of
their country rocks at (or slightly below) the present
level of exposure. They are the only rocks in the study
area for which such a relationship can be demonstrated. It
is interesting to speculate also that the Manak Island
Granitoid, which is compositionally similar to the
Brumwater Granite (note, for example, their coincident REE
patterns) is a product of the same process in the east of
the area. This unit, however, is not obviously
xenolith-rich.

The Island Harbour Bay Intrusive Suite was not
examined directly in this study, but apparently has
elements of both settings (Ryan et al., 1983; I.Ermanovics,
pers.comm., 1988). The outer portion is rich in gneissic
xenoliths, and has a migmatitic contact with surrounding
gneisses. In contrast, the inner portions of the body are
massive and relatively xenolith-free. The presence of
dioritic and tonalitic rocks, however, indicates that the
suite cannot be _entirely_ of anatectic origin, as such rocks
are impossible to derive by partial melting of the Archean
gneisses, which have a bulk composition approximating
tonalite or granodiorite (Korstgård and Ermanovics, 1985).

Geochemical Associations

Syn-tectonic Makkovikian plutonic rocks are also
divisible into two associations on geochemical grounds.
These partially correspond to those outlined above.

The Long Island Quartz Monzonite and Kennedy Mountain
Intrusive Suite define a metaluminous-peralkaline
association that shows Fe-enrichment and sporadic
peralkaline compositions in the latter. They define smooth,

continous, major and trace element trends, that terminate
with evolved high-silica granites of the Kennedy Mountain
Suite. They are regarded here as genetically related,
possibly as a magma sequence derived by fractionation of a
single parent. This association is characterized by
distinct enrichment in fluorine, Zn, HFS elements and REE.

In contrast, remaining syn-tectonic granitoid units
define a mostly peraluminous association. Peralkaline rocks
are absent, and F/F+M ratios are lower at a given SiO_2
content, except for the Melody Granite (see below). These
show (as a group) significantly lower F, Zn, HFS element
and REE abundances, indicating a quite different origin (or
source material). The Pitre Lake Granite has a distinct
mineralogy and geochemistry (high Li, Rb, Th, low LREE)
consistent with field evidence for a metasedimentary
source. The Melody Granite is enigmatic; it is variably
peraluminous, but in most other respects (including trace
element geochemistry), it is akin to metaluminous -
peralkaline granites of the Kennedy Mountain Suite, and
probably has a similar origin.

Origin of Compositional Variations

Metaluminous - Peralkaline Association : This
association is characterized by geochemical trends that are
explicable either by fractional crystallization or unmixing
of anatectic residue (e.g. White and Chappell, 1977; Wall
et al , 1987). In the case of the Kennedy Mountain Suite,
alkali metasomatism has superimposed scatter on LFS element
trends (see below). In the granite quaternary system, this
association evolves from the plagioclase volume to the
plagioclase - K-feldspar cotectic, and then terminates
close to the eutectic minimum (Figure 3.6). Such
characteristics favour control by crystal fractionation,
also indicated by the porphyritic nature of many rocks.

Trends for Ba, Sr, K and Rb (Figure 3.10) are close to those predicted by idealized fractionation of plagioclase (± mafics) in the Long Island unit, and plagioclase ± K-feldspar in the Kennedy Mountain Suite (also the Melody Granite). Curvature of the Ba-Sr trend probably reflects a greater proportion of K-feldspar fractionation at high SiO_2 contents. This interpretation is consistent with observed phenocryst assemblages in these rocks. It is also consistent with the prominent negative Eu anomalies in REE patterns. There is some evidence of accessory mineral fractionation in the most evolved rocks. Late crystallization of accessories, and resultant HFS and REE enrichment, is a common feature of F-enriched granitoids with high K+N/A ratios, and probably reflects retention of these elements in the melt as alkali-fluoride or alkali-zirconosilicate complexes (Collins et al., 1982; Linthout, 1984; Whalen et al., 1987).

Peraluminous Association : Field evidence for local anatectic derivation of the Brumwater and Pitre Lake Granites implies that partial melting had greater influence on geochemistry than any subsequent fractional crystallization (c.f. White and Chappell, 1977). The Brumwater Granite has unusually high Sr and low Rb for an anatectic melt; this probably reflects incorporation of plagioclase-bearing restite. Such material is also required to explain the absence of a negative Eu anomaly (Figure 3.11). The low HFS element and REE abundances in all peraluminous units (except Melody Granite) indicate that sphene and zircon were "removed" early in crystallization; it is likely that this reflects their stability in anatectic residuum. Low Y in most of these units may indicate similar residual hornblende. Large, euhedral

sphene crystals in some Island Harbour Suite granitoids
(B.Ryan, pers. comm., 1988) suggests fractional
crystallization in this particular case. Strong La
depletion and Y enrichment in the Pitre Lake Granite
probably indicates an allanite or monazite-bearing
residuum. (c.f. Mittlefeldt and Miller, 1983).

Metasomatism in The Kennedy Mountain Intrusive Suite

High-silica granitoids of the Kennedy Mountain
Intrusive Suite include a population that has N/N+K ratios
beyond the normal range of magmatic rocks. There is no
systematic geographic variation in N/N+K; these ultrasodic
samples appear to be dispersed randomly through areas of
"normal" composition.

It is suggested that this reflects deuteric or
hydrothermal albitization related to late-magmatic or
post-crystallization processes. Similar alkali metasomatism
has been documented in felsic volcanic rocks of the Upper
Aillik Group by White and Martin (1980) and Evans (1980),
and in this study (see Chapter 7). White and Martin (1980)
suggested that the Upper Aillik Group alteration is
analogous to fenitization, a process commonly associated
with alkaline magmas. They also recognized K-metasomatism,
which they interpreted to occur at a lower temperature than
the predominant albitization. The alteration in the Kennedy
Mountain Suite is interpreted here to record the same event
that affected the Upper Aillik Group; this is consistent
with the inferred age of the former (> 1800 Ma) and
measured ages for the latter (1860 - 1810 Ma). The
predominance of Na-metasomatism is consistent with a deeper
level, plutonic environment (c.f. White and Martin, 1980).

Since the Kennedy Mountain Suite granites cut the
Upper Aillik Group, this metasomatism and alteration must
have been post-volcanic in timing. There are, however, no
firm constraints on the time interval between volcanism,
granitoid intrusion and alteration, and they may have
followed each other rapidly. As will be shown later
(Chapter 7), there are strong geochemical similarities
between the Kennedy Mountain Suite and Upper Aillik Group
felsic volcanic rocks, that suggest partial equivalence.

White and Martin (1980) suggested that trace element
variations, particularily U, Th, Pb, Zr and F, could be
linked to the degree and type of alteration in the Upper
Aillik Group. In contrast, this study suggests little
coherent variation, except for some LFS trace elements and
Li, which are variably depleted in metasomatized granites.
The data of White and Martin (1980), however, included
mineralized samples which had suffered silica loss in
association with albitization and K-metasomatism. None of
the granite samples in this study display such extreme
alteration, and silica levels remain relatively constant
with alteration (e.g. Figures 3.5; 3.6).

CHAPTER FOUR
POST-TECTONIC MAKKOVIKIAN
PLUTONIC ROCKS

Chapter Abstract

Post-tectonic Makkovikian plutonic rocks are generally undeformed, except in the south of the area, where they have generally east-trending (Grenvillian) foliations. U-Pb zircon and Rb-Sr ages indicate that most were emplaced ca. 1800 Ma ago, although some may be 1760 Ma old or younger. They are divisible into a monzonite to quartz syenite association, and three suites of siliceous rocks dominated by granite and alkali-feldspar granite.

The Numok Intrusive Suite ranges from plagioclase-porphyritic monzonite to hypersolvus, alkali-feldspar quartz syenite. These rocks are biotite and hornblende-bearing, with variable amounts of clinopyroxene. The syenitic rocks locally contain fayalite. SiO_2 contents are moderate (58-66%), but all members of the suite are alkali-rich and potassic. Trace element patterns are characterized by HFS element and REE enrichment. LFS elements (e.g. Rb) approach abundance levels typical of high-SiO_2 units. Geochemical trends suggest that the Numok Suite evolved by fractional crystallization of plagioclase and K-feldspar (± mafic minerals). The parent magmas must have been at least as mafic as monzonite to generate the observed compositional range.

The Strawberry Intrusive Suite comprises several discrete plutons consisting of closely similar fluorite-bearing, K-feldspar porphyritic, subsolvus, biotite granite and alkali-feldspar granite. Sodic amphibole (reibeckite or arfvedsonite) occurs locally in some of these. The plutons were emplaced at shallow depths, and probably had low viscosities and solidus temperatures as a consequence of their fluorine enrichment. They show direct evidence of biotite (± hornblende) and accessory mineral (zircon, allanite) fractionation in the form of cumulate mafic mineral layers. The close similarity of five plutons over a lateral distance of 125 km indicates identical sources and/or processes. The Lanceground Intrusive Suite comprises three plutons of K-feldspar porphyritic, variably hypersolvus, biotite-hornblende quartz syenite and alkali-feldspar granite. These locally contain fayalite, reibeckite and aegirine-augite, and locally resemble syenites of

the Numok Intrusive Suite. The Big River Granite is a regional
unit of K-feldspar porphyritic, subsolvus, biotite- hornblende
granite and alkali-feldspar granite that has mantled- feldspar
phenocrysts with plagioclase interiors (pseudorapakivi texture).

In geochemical terms, all siliceous granitoid suites are
closely similar, and resemble the Numok Suite. They are
metaluminous to weakly peralkaline, potassic and Fe-enriched
(F/F+M > 0.85). The more evolved members lie close to the
ternary minimum in the Q - Ab - Or - An system. All are
characterized by enrichment in fluorine, HFS elements (e.g. Zr,
Nb and Hf), REE (Y, La, Ce, Sm), depletion in Ba and Sr, and
moderate enrichment in incompatible LFS elements (Rb, U and Th).
Trace element patterns vary in detail; for example, the
Lanceground Suite has the greatest HFS and REE enrichment,
whereas the Strawberry suite is richest in fluorine. The Big
River Granite is generally less evolved and more variable in
composition than the smaller plutons that constitute the
Strawberry and Lanceground Suites.

Geochemical trends indicate that all evolved primarily by
fractionation of plagioclase and K-feldspar (± mafic minerals).
Hypersolvus suites show little or no evidence of plagioclase
extraction, and K-feldspar fractionation dominated the later
stages in the subsolvus suites. In the the Strawberry Intrusive
Suite, geochemical variation caused by liquid-state processes
(e.g. thermogravitational diffusion, convective fractionation)
has been superimposed on trends generated by crystal-liquid
processes. Some fractionation of accessory phases and biotite
also occurred in this suite.

These suites collectively have a strong affinity to the
syn-tectonic metaluminous-peralkaline association described in
Chapter 3. This is most evident for the F-enriched granites,
which resemble the syn-tectonic Kennedy Mountain Intrusive Suite
in both geochemical and petrological terms, if the effects of
deformation in the latter are disregarded. A close temporal
relationship between syn- and post-tectonic Makkovikian
plutonic associations is indicated by geochronological data,
which cluster around 1800 Ma in both. The consanguinous and
partly contemporaneous nature of these associations suggests
that they represent a single episode of magmatism that
transcended Makkovikian deformation, which may also have been
inhomogeneous in its effects. There are, however, no obvious
post-tectonic equivalents of the syn-tectonic Makkovikian
peraluminous association described in Chapter 3.

Introduction

This association comprises largely undeformed plutonic rocks. There are few field criteria to separate these from similarly undeformed Labradorian plutonic rocks (Chapter 5) and this association is presently defined mostly by geochronological data. As discussed previously (Chapter 2, Chapter 3), "post-tectonic" is a label of convenience; it does not necessarily mean that they are significantly younger than the "syn-tectonic" Makkovikian association; in fact, U-Pb geochronological data (Krogh et al., in prep., see below) suggest a close similarity in age. The term also does not imply a universal absence of foliations; in the south of the area, these rocks locally display evidence of deformation. However, the predominance of east-trending fabrics (parallel to the Grenville Front Zone) in such areas suggests that these represent Grenvillian, rather than Makkovikian, deformation. Post-tectonic Makkovikian plutonic rocks are divided into four main associations (Figure 4.1; Table 4.1).

The Numok Intrusive Suite ranges in composition from monzodiorite to quartz syenite, but is dominated by quartz monzonite. The Strawberry Intrusive Suite includes several plutons of distinctive fluorite-bearing granite. The Lanceground Intrusive Suite consists of three quartz syenite to granite plutons that locally show hypersolvus characteristics. The Big River Granite is an extensive body of porphyritic granite that shows distinctive mantled feldspar ("pseudorapakivi") textures.
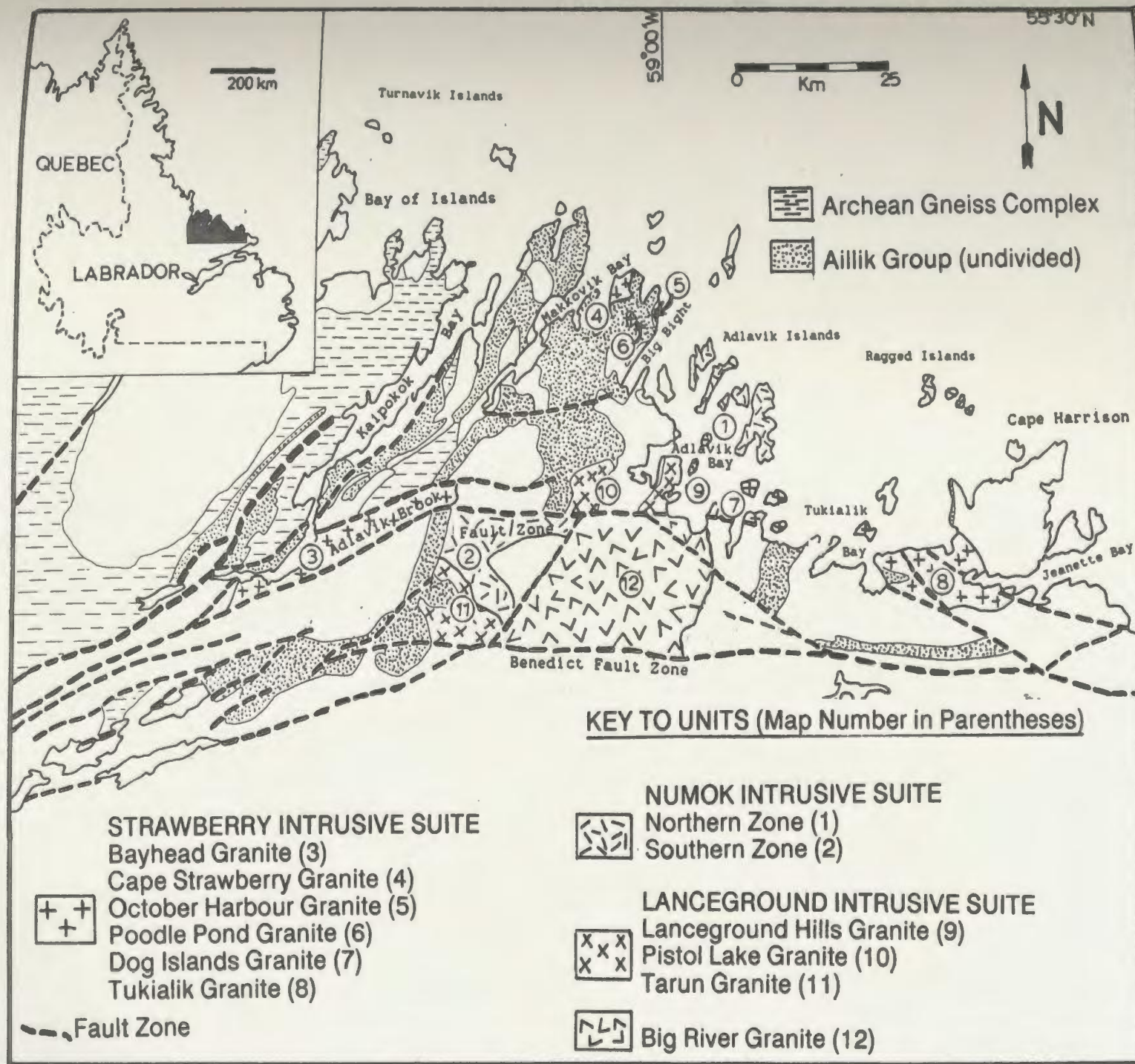
Figure 4.1. Summary map illustrating the distribution and extent
of post-tectonic Makkovikian plutonic units.

Table 4.1. Key features of post-tectonic Makkovikian plutonic units.

Map Unit	Suite/Unit/Age	General Characteristics	Textural Characteristics
	NUMOK INTRUSIVE SUITE	Homogeneous, white, grey or pink, variably porphyritic, massive Hb-Bi (+/- Px) monzonite, quartz monzonite and lesser syenite. Undeformed and massive in all areas except at the western margin of the northern zone near Adlavik Bay. K-feldspar +/- plagioclase phenocrysts, K-fsp more abundant.	Coarse grained, commonly porphyritic, with phenocrysts of K-fsp and Plag, up to 2 cm in diameter. Hb and Bi form euhedral crystals, up to 5-10 mm in length. Interstitial material is mostly Qz and K-fsp. Inclusions of gabbro and diorite occur locally, particularly near Adlavik Bay, but the unit is mostly inclusion-poor.
20.1 20.2	Monzonite - Quartz Monzonite 1801 +/- 2 Ma [U-Pb Zircon] (Krogh et al., in prep.)		
21.1 21.2	Syenite and Quartz Syenite 1801 +/- 2 Ma [U-Pb zircon]	Homogeneous, grey-green to brown, K-fsp porphyritic, Cpx-Hb-Bi (+/- Fa) syenite, alkali-fsp syenite, qz-syenite and granite. Locally hypersolvus. Massive in north; locally deformed in south. Displays intense surface weathering to yellow-brown gravel. Blue quartz occurs in silicic rocks.	Commonly coarse to very coarse grained, with euhedral to ovoidal phenocrysts of coarse perthitic K-fsp. Locally fine-grained syenite. Mafic minerals and quartz are interstitial. Generally inclusion-poor. East-trending fabrics common in southern zone (Grenvillian?).
22.2	Plagiophyric Monzonite	Grey to brown, plag-porphyritic Px-Hb monzodiorite and monzonite. Forms a mappable unit only in southern zone, but similar rocks occur locally in the northern zone.	Coarse to very coarse grained, with large, rounded to subhedral plag phenocrysts. Mafic minerals, Qz and K-fsp are interstitial to locally oikocrystic. Unit locally has a cumulate texture, but is not layered.
23.0	STRAWBERRY INTRUSIVE SUITE Bayhead Granite 1570 +/- 50 Ma [K-Ar Bi] (Wanless et al., 1970)	All units (except Poodle Pond) consist dominantly of massive, homogeneous, white, pink, orange or brick-red, K-feldspar-porphyritic biotite granite, quartz syenite and alkali-fsp granite, commonly with conspicuous purple fluorite. Fine-grained phases (including Qz-Fsp porphyry) are present locally in most units, and dominate the Poodle Pond Granite. The Bayhead granite is the most melanocratic, and the Tukialik granite is the most potassic. Cape Strawberry Granite is the most variable texturally.	Commonly coarse to very coarse grained or pegmatitic in texture. Fine-grained miarolitic rocks occur as marginal phases and minor bodies. Related Qz-Fsp porphyry and pegmatite dykes and veins cut adjacent units. Commonly porphyritic or megacrystic. K-feldspar phenocrysts up to 3 cm in diameter. Dog Islands Granite is locally Qz-porphyritic. Xenolith-rich only in contact zones. Tuffisite veinlets and breccia zones, with Fl-Bi rich matrix, cut xenoliths and coarse-grained granite. Distinctive mafic mineral layering, with trough-bedded "cumulate" geometry.
24.1	Cape Strawberry Granite ca. 1760 Ma [U-Pb zircon] (Krogh et al., in prep.) 1565 +/ 50 Ma [K-Ar Bi] 1600 +/ 34 Ma [K-Ar Bi] (Wanless et al., 1970) 1694 +/ 56 Ma [Rb-Sr WR, composite] (this study)		
24.3 24.2 25.0 26.0	Poodle Pond Granite October Harbour Granite Dog Islands Granite Tukialik Granite		
27.0	LANCEGROUND INTRUSIVE SUITE Lanceground Hills Granite 1692 +/- 32 Ma [Rb-Sr WR] (this study, age probably disturbed)	All units consist dominantly of homogeneous, pink to buff or brown, K-fsp porphyritic, quartz syenite granite and alkali-fsp granite. Lanceground Hills and Pistol Lake Granites are massive and undeformed in most places; Tarun granite is variably foliated and recrystallized. Locally similar to syenite unit of the Numok Intrusive Suite.	Medium to coarse grained, commonly K-feldspar porphyritic, with euhedral phenocrysts of coarse perthitic K-fsp (Mi), with relict simple twinning (originally Or?). Many examples lack plagioclase and are hypersolvus granites. Rounded mafic clots occur locally, but inclusions are uncommon.
28.0 29.0	Pistol Lake Granite Tarun Granite		
30.1	Big River Granite 1798 +/- 28 Ma [Rb-Sr WR] (this study)	White, pink and brick-red, K-fsp porphyritic Bi-Hb granite and alkali-feldspar granite, lesser quartz monzonite to quartz syenite. An equigranular variant (30.2) occurs on a mappable scale in the southeast and northwest of the body. The southern part of the unit has variably developed augen texture and cataclastic fabric (Grenvillian).	Commonly coarse to very coarse-grained, with K-fsp phenocrysts up to 5 cm in size. Distinctive pseudorapakivi texture (K-fsp rims on Plag cores) is developed widely. Texture locally varies to seriate. Unmantled Plag phenocrysts occur locally, and small K-fsp phenocrysts lack plagioclase cores. Foliations in south defined by K-fsp augen / mafic aggregates.
30.2	(equigranular phase)		

Table 4.1 (continued)

Key Field Relationships	Mineralogy	Petrography
Western boundary of northern zone is a complex agmatite, including blocks of gabbro and diorite. This zone has a variably developed N-trending foliation (see text). Relationship with syenite unit is gradational in the northern zone. On Adlavik Islands, unit is cut by Qz-Fsp porphyry dykes correlated with adjacent Dog Islands Granite.	Qz (5-20%) Mi (30-50%) Plag (An30-40; 30-50%) Hb + Bi (5-25% total, subequal) Cpx (relict, < 5%) Accessory Sph, Zr, Ap, Fe-Ox Rare All, Fl	Well-preserved Igneous textures and interstitial quartz crystals. K-fsp (Mi) phenocrysts are variably perthitic, and larger than coexisting Plag phenocrysts. Plag phenocrysts locally have K-feldspar rims. Mafic minerals form subhedral to euhedral crystals / aggregates. Hb locally contains relict Cpx cores.
Relationship to Aillik Group is unknown, but probably intrusive. Contact with quartz monzonite unit appears gradational in the northern zone, but they are separated by plagiophyric monzonite in southern zone (unit 22).	Qz (0-15%), K-fsp (40-80%) Plag (5-30%, excluding perthite) (free Plag locally absent) Cpx + Hb + Bi (5-25% total) (Cpx + Bi > Hb) Fayalitic Olivine (relict, <5%) Some variants lack Hb. Accessory Zr, Ap, Sph.(Zr prominent)	Igneous textures well-preserved in northern zone, variable recrystallization in southern zone. Perthitic K-fsp phenocrysts have relict simple twinning (originally Or?) Cpx is green, Fe-rich variety. Bi is red in color, also Fe-rich. Olivine strongly altered to Fe-Oxide.
Relationships with other units of Mumok Suite unknown. Probably a mafic end-member of the monzonite-quartz monzonite unit, which it locally resembles.	Qz (0-10%) Mi (15-40%) Plag (An35-50; 30-70%) Cpx + Bi + Hb (10-25% total) (Cpx > Bi > Hb, except if altered) Opx (rare < 5%) Accessory Ap, Sph, Fe-Ox.	Igneous textures are well-preserved. Plag phenocrysts are locally zoned. Mafic minerals in fresh variants are Cpx and lesser Bi. In more altered variants, Plag is strongly saussuritized and mafics are retrogressed to Act-Ep-Sph aggregates.
Cape Strawberry Granite intrudes Upper Aillik Group, but fine-grained granite is difficult to distinguish from country rocks. Contacts range from clean, sharp and intrusive, to hybrid zones of interaction with and alteration of country rocks. Qz-fsp porphyry dykes correlated with Dog Islands granite cut qz-monzonite of Mumok Intrusive Suite. Cape Strawberry Granite is associated with stockwork Mo-Py mineralization. Dog Island Granite hosts disseminated Cu-Pb mineralization. Cu-Mo and Pb-Zn vein mineralization in Aillik Group country rocks near to granites.	Qz (20-45%) Mi (40-70%) Plag (An15-25; 10-35%) Bi +/- Chl (1-6%) (Bi altered to Chl) Hb (relict, altd to Bi) rare blue sodic amphibole Accessory Zr, Sph, All, Fl Dog Islands Granite includes a syenitic phase that locally contains a green relict Cpx, possibly Ae-augite. Fine-grained phases of Cape Strawberry Granite contain poikolitic blue amphibole.	Igneous textures well-preserved. K-fsp (Mi) is variably hematized, coarse patch perthite. Plagioclase normally occurs in groundmass only, but forms local phenocrysts in Baybead Granite. Qz is anhedral to interstitial. Red-brown biotite is variably altered to chlorite and Fe-Ox along cleavage traces. In strongly hematized rocks, Bi is totally chloritized. Blue-green Hb occurs locally as a relict phase, altered to Bi. Fl is present interstitially, in mafic aggregates, and tiny veinlets. "Cumulate" layers contain euhedral Bi, Hb, Zr, All.
Dykes correlated with Lanceground Hills Granite cut agmatitic western contact zone of Mumok Intrusive Suite. Pistol Lake Granite intrudes Upper Aillik Group, and is cut by gabbro (possibly Adlavik Suite?) Tarun Granite is fault-bounded, and lies topographically below Qz-Fp porphyry at White Bear Mountain, that is grouped with Upper Aillik Group.	Qz (5-35%) Mi (50-80%) Plag (An10-25; 0-25%, excl. perthite) Bi (red, Fe-rich) + Hb (0-10% total) Cpx (relict, < 2%, Ae-augite ?) Rare blue sodic amphibole. Fayalitic olivine (rare, altd to Fe-Ox) Accessory Zr, All, Fl, Sph Biotite typically red variety Amorphous Fe-Ox clots are probably after olivine.	Igneous textures well-preserved in north, recrystallized in south. Plagioclase phenocrysts are rare. Quartz shows interstitial habit. Hb and Bi interstitial, locally poikilitic. Hb crystals locally show relict pale green Cpx cores. Fluorite interstitial, associated with mafic minerals. Euhedral zircons up to 4 mm length.
Contact relations unknown. Western boundary of unit is a major fault escarpment along Big River. Southern boudary is formed by Benedict Fault system. Eastern boundary is difficult to define. Foliated grey granitoids near eastern edge are atypical, and may be a screen of older material. Granitoid gneisses south of Benedict fault zone may be deformed equivalents.	Qz (20-35%) Mi (40-70%) Plagioclase (An20-35; 10-40%) Hb + Bi (2-10% total, Hb > Bi) (Hb is blue-green in colour) Cpx (relict, < 2%, Ae-augite?) Accessory Sph, All, Ep, Zr Rare Fl, disseminated Py. Equigranular variants have similar mineralogy, but are richer in quartz and biotite, poorer in Hb.	Igneous textures are best preserved in northern part of unit. Composite phenocrysts are Mi-perthite with zoned, saussuritized, plag cores. Quartz has variably interstitial habit. Mi and Plag both occur in groundmass. Hb and Bi form clots, associated with Fe-Ox and accessory minerals. Foliated and cataclastic variants show retrogression of mafic minerals to Chl, Ep and Sph.

4.1 GEOLOGY AND PETROLOGY

Key field and petrographic characteristics of post-tectonic Makkovikian plutonic rocks are summarized in Table 4.1.

4.1.1 Numok Intrusive Suite

Definition and Distribution

This is a new name introduced for monzonite, quartz monzonite, syenite and quartz syenite exposed in two areas referred to below as the northern and southern zones (Figure 4.1). These rocks were previously grouped with the Adlavik Intrusive Suite by Kerr (1986, 1987), because they resemble some of its more differentiated variants. U-Pb geochronological data, however, indicate that this interpretation is incorrect (see below). The northern and southern zones of the Numok Suite are interpreted as disrupted halves of an originally continuous pluton. Three compositional units (not named) are defined within the suite, and are described below in order of abundance.

Monzonite and Quartz Monzonite

In the northern zone, this unit corresponds broadly with Unit 23 of Gower et al. (1982); in the southern zone, it is a new subdivision of their Unit 26. The unit is dominated by homogeneous, coarse grained biotite-hornblende monzonite, quartz monzonite and (locally) syenite (Table 4.1; Plate 4.1).

In the northern zone, on the Adlavik Islands, this unit appears to be gradational with syenite and quartz syenite.
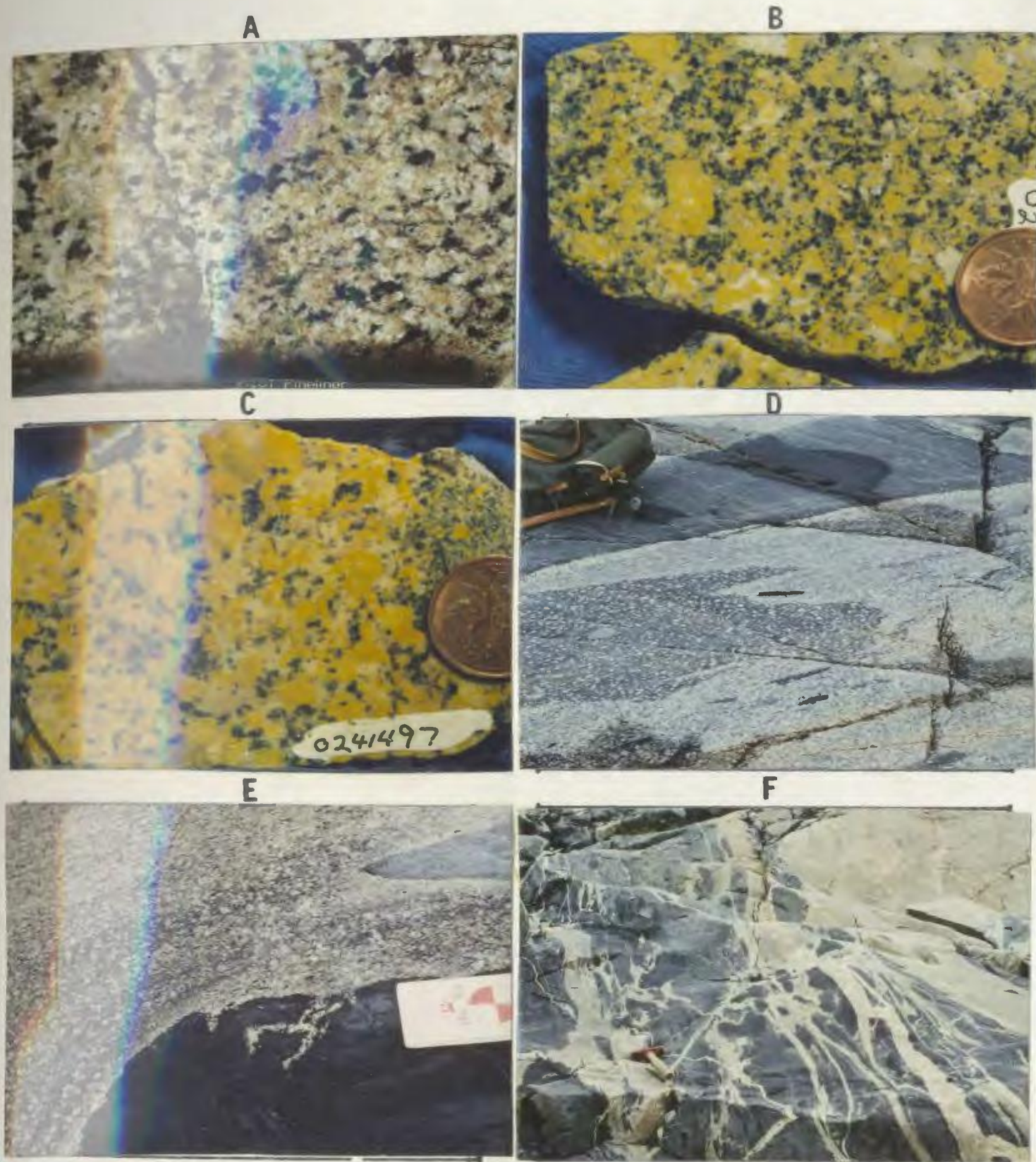
Plate 4.1. Features of the Numok Intrusive Suite (monzonite - quartz monzonite unit). (a) Typical homogeneous quartz monzonite, Long Tickle Island. (b) Porphyritic variant, same area. (c) Typical example with part of cognate xenolith, Big River Area. (d) Undeformed agmatitic border zone, north side of Adlavik Bay. (e) Flow fabric around mafic xenolith in agmatite. (f) Foliated agmatite cut by later fine-grained granitoid material, south side of Adlavik Bay. Slabs are stained for K-feldspar.

The western boundary of the unit in the north consists of a complex agmatite zone up to 1 km wide, exposed near the mouth of Adlavik Bay. The northern part of this zone comprises grey-brown quartz monzonite containing numerous stoped blocks of diabase, gabbro, leucogabbro and porphyritic diorite, some of which display cumulate layering. A fabric around some of the larger inclusions is probably a flow feature, as the inclusions themselves are undeformed. On the south shore of Adlavik Bay, less than 1 kilometre along strike, the same agmatite has a north-trending foliation, present also in the mafic inclusions, which are here transformed to amphibolite. This complex zone was previously interpreted in terms of forcible emplacement of quartz monzonite into gabbro and diorite of the adjacent Adlavik Intrusive Suite (Gower, 1981; Gower et al.,1982; Kerr,1986). However, U-Pb ages from the agmatite neosome at Adlavik Bay indicate crystallization at 1801 ± 2 Ma (Krogh et al., in prep.) , indicating that the mafic inclusions are older than 1800 Ma, and are hence <u>unrelated</u> to the nearby Adlavik Suite, dated at 1649 ± 1 Ma (Krogh et al., in prep). The fabric in the deformed part of the zone may result from syn-emplacement deformation at the original margin of the Numok Suite, or it may be associated with emplacement of the adjacent Adlavik Intrusive Suite. As it affects both paleosome and neosome in the agmatite, it must be younger than 1801 Ma. It is clearly of local extent only, as it dies out quickly to the north.

Excluding this complex western margin, the unit is undeformed and homogeneous in both northern and southern zones, generally inclusion-poor (although it contains sporadic gabbroic blocks) and consistent in both mineralogy and texture (Table 4.1 for details; Plate 4.1).
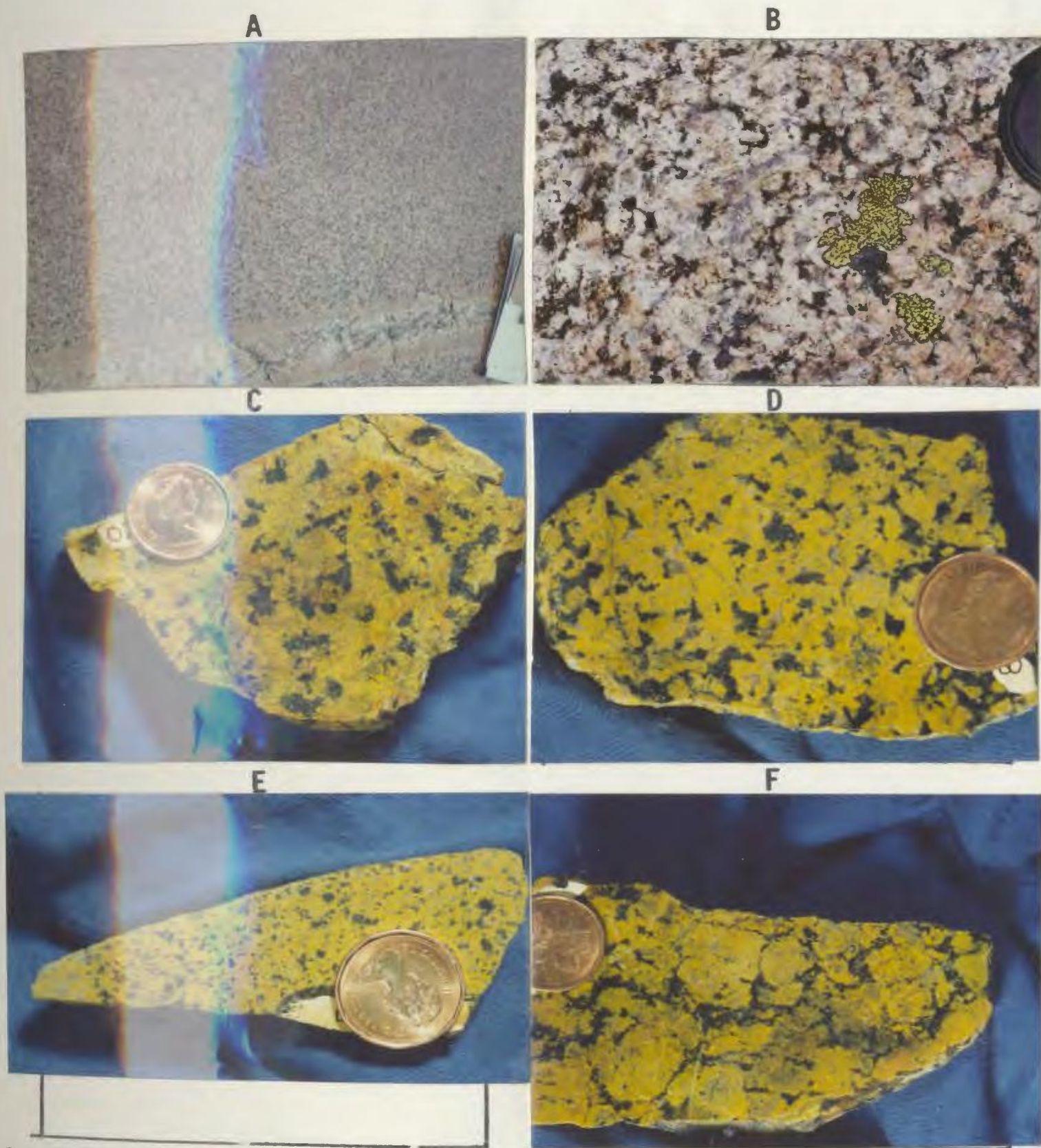
Plate 4.2. Features of the Numok Intrusive Suite (syenite - quartz syenite unit. (a) Homogeneous syenite, Dunn Island. (b). Coarse-grained quartz syenite, north of White Bear Mountain. (c) Hypersolvus, K-feldspar-porphyritic, fayalite-pyroxene syenite, Cape Kitchener. (d) Quartz syenite, ·Kikkertavak Island. (e) Fine-grained phase in same general area. (f) Coarse-grained syenite with ovoidal·phenocrysts and weak deformation, north of White Bear Mountain. Slabs are stained for K-feldspar.

Syenite and Quartz Syenite

This unit occurs on the outer Adlavik islands, but is most extensively exposed in the southern zone. In the north, it corresponds generally with Unit 31 of Gower et al. (1982), and in the south, with the Tarun Syenite of Gandhi et al. (19)9) and Gower et al. (1982; Unit 26c). Similar rocks occur on the Ragged Islands (Gower, 1981), suggesting that it may also be regionally extensive in the north. It is dominated by pink, brown or grey-green, coarse grained, K-feldspar porphyritic, pyroxene - biotite - hornblende syenite, quartz syenite and alkali-feldspar syenite with interstitial quartz and mafic phases (Table 4.1; Plate 4.2). Intense weathering to a yellow-brown gravel is characteristic in many areas, particularly on the Adlavik Islands. The southern zone displays variable recrystallization and deformation, particularly close to the Adlavik Brook fault zone. Massive syenite from Kikkertavak (Numok) Island has given a concordant U-Pb zircon age of 1801 ± 2 Ma (Krogh et al., in prep.).

Distinctive petrographic features include a green, locally pleochroic, Fe-rich clinopyroxene and red-brown biotite. Pyroxene is commonly mantled by variable amounts of hornblende. Variably retrogressed fayalitic olivine occurs locally, surrounded by clots of amorphous iron oxide and hydroxide ("iddingsite"). Patches of this material in other samples are probably pseudomorphs after fayalite. The intense weathering is probably related to the former presence of fayalite; similar effects are present in fayalite-bearing rapakivi granites elsewhere in Labrador (Hill, 1982; Ryan, pers.comm., 1988).
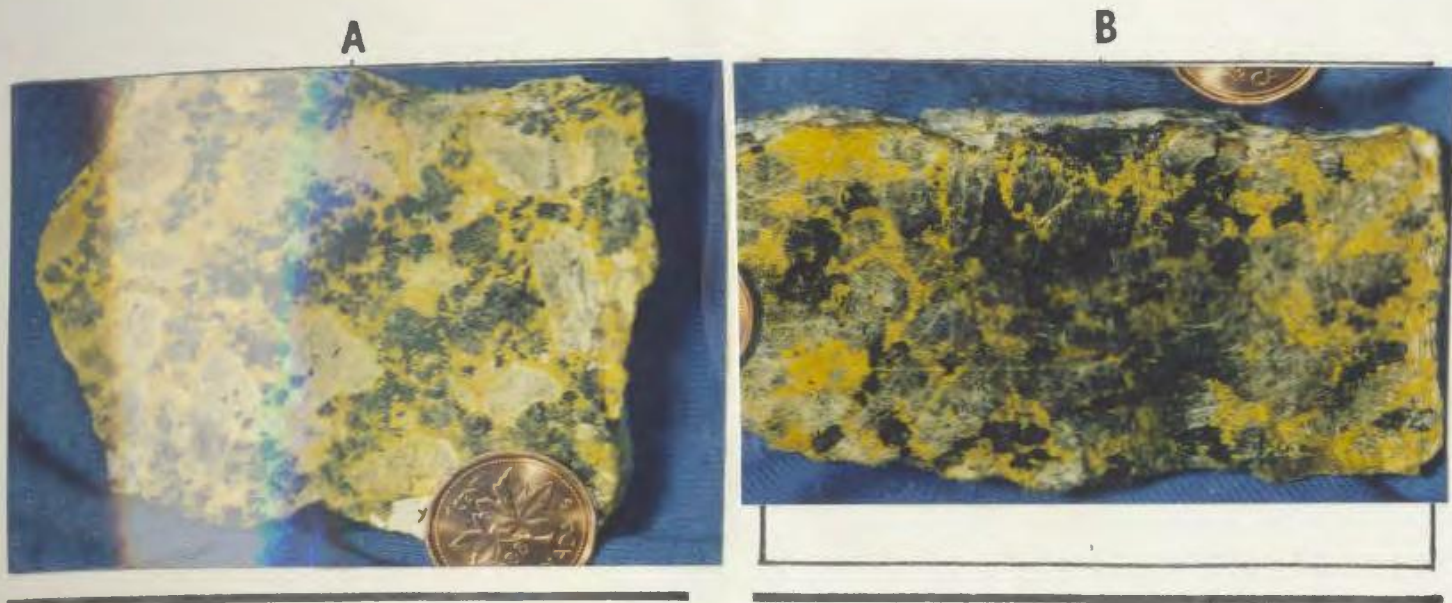
Plate 4.3. Features of the Numok Intrusive Suite (plagiophyric monzonite unit). (a) Monzonite with zoned, ovoidal, plagioclase phenocrysts and interstitial pyroxene-amphibole. (b) Plagioclase-rich variant (cumulate ?), with oikocrystic mafic minerals. Both samples from area west of Big River. Slabs are stained for K-feldspar.

Plagiophyric Monzodiorite and Monzonite

This unit is sandwiched between the quartz monzonite
and quartz syenite units in the southern zone. It consists
of distinctive, plagioclase - porphyritic, pyroxene-
hornblende monzodiorite and monzonite (Table 4.1; Plate
4.3).

Textures in many samples are of "cumulate" aspect, and
mafic minerals commonly show an oikocrystic habit. Fresh
variants are augite (± hypersthene) - biotite monzonites
with minor amphibole, but altered variants dominated by
saussuritized plagioclase and fine-grained actinolite are
more common. The unit is probably a mafic variant of the
monzonite to quartz monzonite unit, which is locally
plagioclase-porphyritic. The rounded, zoned plagioclase
phenocrysts impart a distinctive texture.

4.1.2 Strawberry Intrusive Suite

Definition and Distribution

Strawberry Intrusive Suite is a new name proposed for
several discrete plutons scattered over an east-west
distance of 125 km (Figure 4.1). All show very similar
characteristics, and they are considered to be equivalent.
Each pluton is dominated by coarse grained, homogeneous,
white, pink or red, K-feldspar porphyritic to megacrystic,
biotite granite, commonly with accessory fluorite (Table
4.1; Plates 4.4 and 4.5). The granites from the type area
(Cape Strawberry) are described in most detail below.

Bayhead Granite

This is a new subdivision of Unit 27 of Gower et al. (1982). Its southern boundary is formed by the Adlavik Brook fault zone, and its northern boundary by an inferred fault. Contact relations are thus unknown. No displaced equivalent of the Bayhead Granite has been recognized south of the Adlavik Brook fault zone, suggesting that it was either restricted to the north side or perhaps that the (presumably upthrown) block to the south represents a level of the crust below its emplacement level. K-Ar data from this unit (Wanless et al., 1970) gave an age of 1570 ± 50 Ma. On the basis of correlation with the Cape Strawberry Granite, it is considered here to be ca. 1760 Ma old (see later discussion).

The Bayhead Granite is the least differentiated pluton in the Strawberry Suite; it is relatively melanocratic (up to 10% total mafic minerals), locally plagioclase-porphyritic, and commonly contains minor relict amphibole. Most of the unit is homogeneous, although it includes a few gabbroic blocks up to 10 m in diameter. Faint mafic mineral layering is present locally (see below for discussion).

Cape Strawberry Granite and Related Rocks

General Information : These form the type locality for the Strawberry Intrusive Suite. The Cape Strawberry and October Harbour Granites correspond to part of Unit 29 of Gower et al.(1982), and the Poodle Pond granite was formerly included in their unit 28a. The Cape Strawberry Granite is dominated by pink or red porphyritic granite, associated with subordinate fine-grained material; the October Harbour Granite tends to be white in color. The
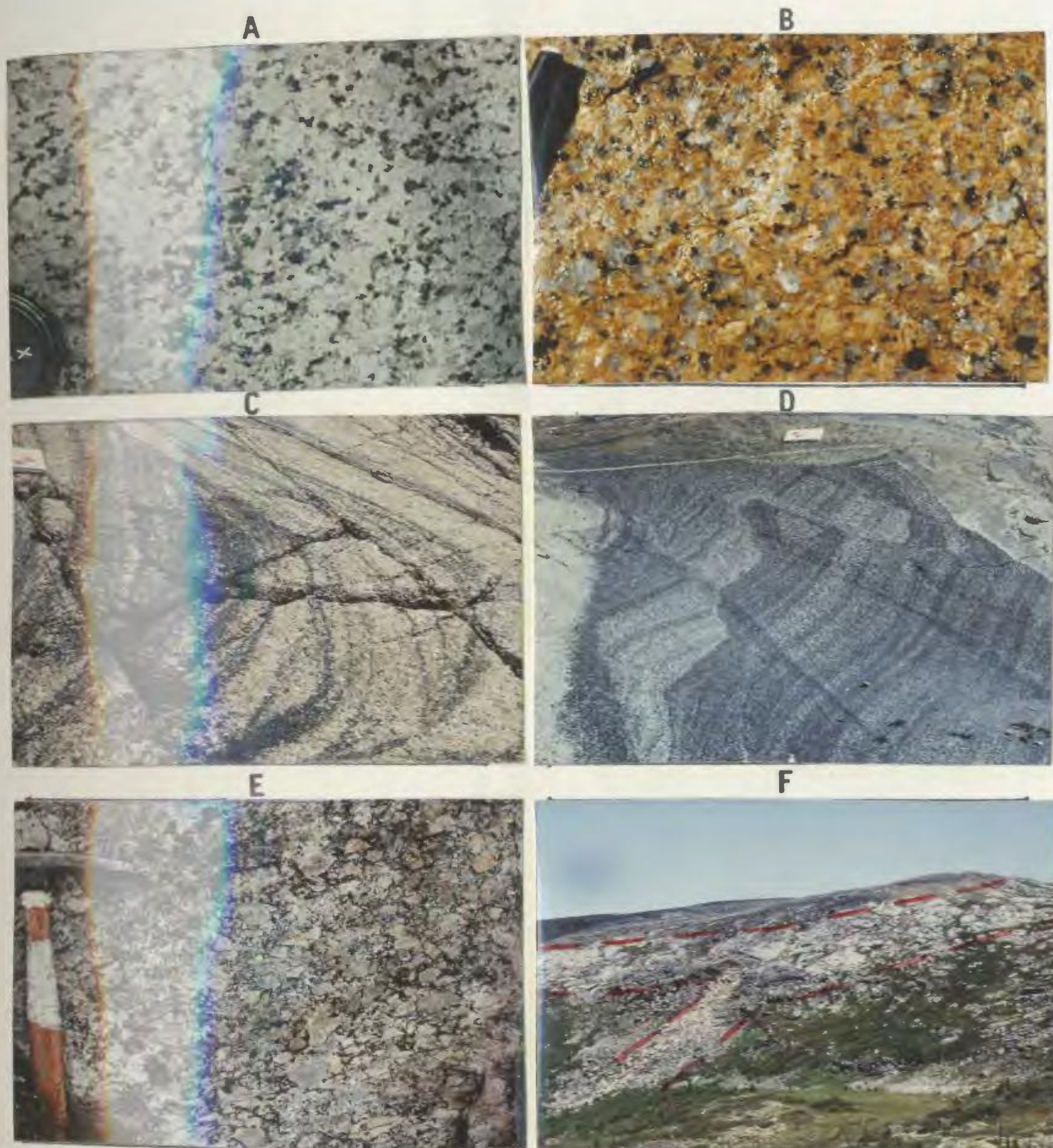
Plate 4.4. Features of the Strawberry Intrusive Suite (see also Plate
4.5).(a) Pale pink, coarse-grained Bayhead granite, Makkovik Lake
area. (b) Orange-red, slightly quartz-porphyritic, hematized Dog
Island granite, Iron Island (typical also of Cape Strawberry Granite).
(c) Trough-bedded, cumulate, mafic mineral layering, near Cape
Strawberry. (d) Rhythmically layered granite block, Ford's Bight. (e)
"Tuffisite" breccia, near southern contact of Cape Strawberry Granite.
(f) Sill of fine-grained, white-weathering granite, with feeder dyke,
near Poodle Pond. Sill has a thickness of 30 - 50 m, and intrudes
Upper Aillik Group (grey in photo).

Poodle Pond Granite consists of two or more sill-like
bodies of medium grained equigranular granite. Single and
multiphase aplite, granite and pegmatite dykes and sheets
cut the Upper Aillik Group throughout the area around Cape
Strawberry. Many are fluorite-bearing, and they are
considered to be minor intrusions related to the Strawberry
Suite. Some pegmatites near Ford's Bight host molybdenite
mineralization (Gower et al., 1982; Wilton and Wardle,
1987).

Geochronology : U-Pb zircon data from the Cape
Strawberry Granite (Krogh et al., in prep.) are discordant
due to Pb loss, but indicate an age of 1800-1760 Ma. The
uncertainty is a function of a lack of fractions near
concordia; if a 1000 Ma (Grenvillian) lower intercept is
assumed (this is shown by other discordant U-Pb zircon data
from the study area), the age could be ca. 1800 Ma, whereas
a regression of the data points alone suggests ca. 1760 ±
15 Ma. In the remainder of this thesis, the latter age has
been employed. A second sample, collected from a zone
containing low-U cumulus zircon (see below) is currently
being analyzed in an attempt to better resolve this
uncertainty[*].

* *NOTE : When the final copy of this thesis was almost
ready for submission, U-Pb data from the second sample
became available (Krogh et al., in prep.). The data are
concordant at 1719 ± 3 Ma, some 40 Ma younger than the ca.
1760 Ma age used herein. This makes little difference to
initial Nd calculations (Chapter 8) and tables and text
have not been amended. The Strawberry Suite is still viewed
as a post-tectonic Makkovikian association, but it is
obvious that the younger limit of the "Makkovikian" time
slot must be now be further revised.*

Wanless et al. (1970) report K-Ar ages of 1565 ± 50 and 1600 ± 34 from the Cape Strawberry Granite. A composite Rb-Sr isochron from plutons of the suite (this study; Chapter 8) yields an age of 1694 ± 56 Ma, but shows evidence of disturbance (i.e. unreasonably low initial Sr isotope ratio).

Field Relationships : Contact zones range from clean, sharp boundaries to zones of interaction and hybridization where the Upper Aillik Group country rocks appear strongly altered. The contacts of the Cape Strawberry granite are steep where exposed on the coast, but the southern contact is more complex, and several enclaves of country rock occur adjacent to it. These are interpreted as roof pendants, and the contact probably dips gently southward.

Xenolith-rich zones near contacts contain fragments of fine-grained granite, Aillik Group metavolcanic rocks, and "hybrid" rock types. Brecciated zones with a biotite-rich matrix are present in xenoliths and in outcrops close to contacts. Alteration, bleaching and pyritization of adjacent country rocks are evident adjacent to contacts. Irregular silicified zones, aplites and pegmatites crosscut the contacts. These features suggest volatile exsolution and hydrothermal activity, which in turn suggest a high level of emplacement. Amphibolites in country rocks at the margin of the October Harbour Granite contain calcite - diopside - andradite ± fluorite skarnoid patches, and the margin of the granite itself contains a pale green-brown (andradite?) garnet that is probably a xenocrystic phase derived from this material.

Compositional and Textural Variation : Granites of the Cape Strawberry area display the greatest textural variation in the Suite. Fine grained, locally miarolitic,

equigranular variants occur locally around contacts,
crosscut contacts, and form the Poodle Pond Granite. A
distinctive fine to medium grained grey phase is present in
the northeast part of the Cape Strawberry body, and occurs
as xenoliths in the coarse facies, suggesting that it is an
early component. Locally, this shows a diffuse foliation
and ghostly inclusion textures suggesting that it could be
an altered Upper Aillik Group porphyry, but in other areas
it appears massive and resembles a fine-grained version of
the granite. It also has a distinctive mineralogy (see
below).

The Cape Strawberry Granite contains distinctive mafic
mineral accumulations with a trough-bedded, locally
cross-bedded, geometry indicative of cumulate processes. It
also contains a single large (10x10 m) block of
rhythmically layered granitoid. The presence of such
features suggests a low viscosity during crystallization of
the granite, probably due to its high fluorine content (see
later discussion).

Petrographic Features : Biotite in the Cape Strawberry
Granite is almost invariably altered to chlorite along
cleavage traces. In strongly hematitic variants, chlorite
is the only mafic silicate. Fluorite is prominent, and
accessory phases such as allanite, apatite, zircon and
sphene are obvious and abundant.

Fine-grained pink phases of the Cape Strawberry granite
have a similar mineralogy to the dominant coarse-grained
phase, but are commonly miarolitic and/or graphic in
texture. The distinctive grey phase described above
contains poikilitic crystals of deep blue reibeckite or
arfvedsonite amphibole, and displays some evidence of
recrystallization. "Cumulate" mafic mineral layers consist

A

B

C

D

E

F
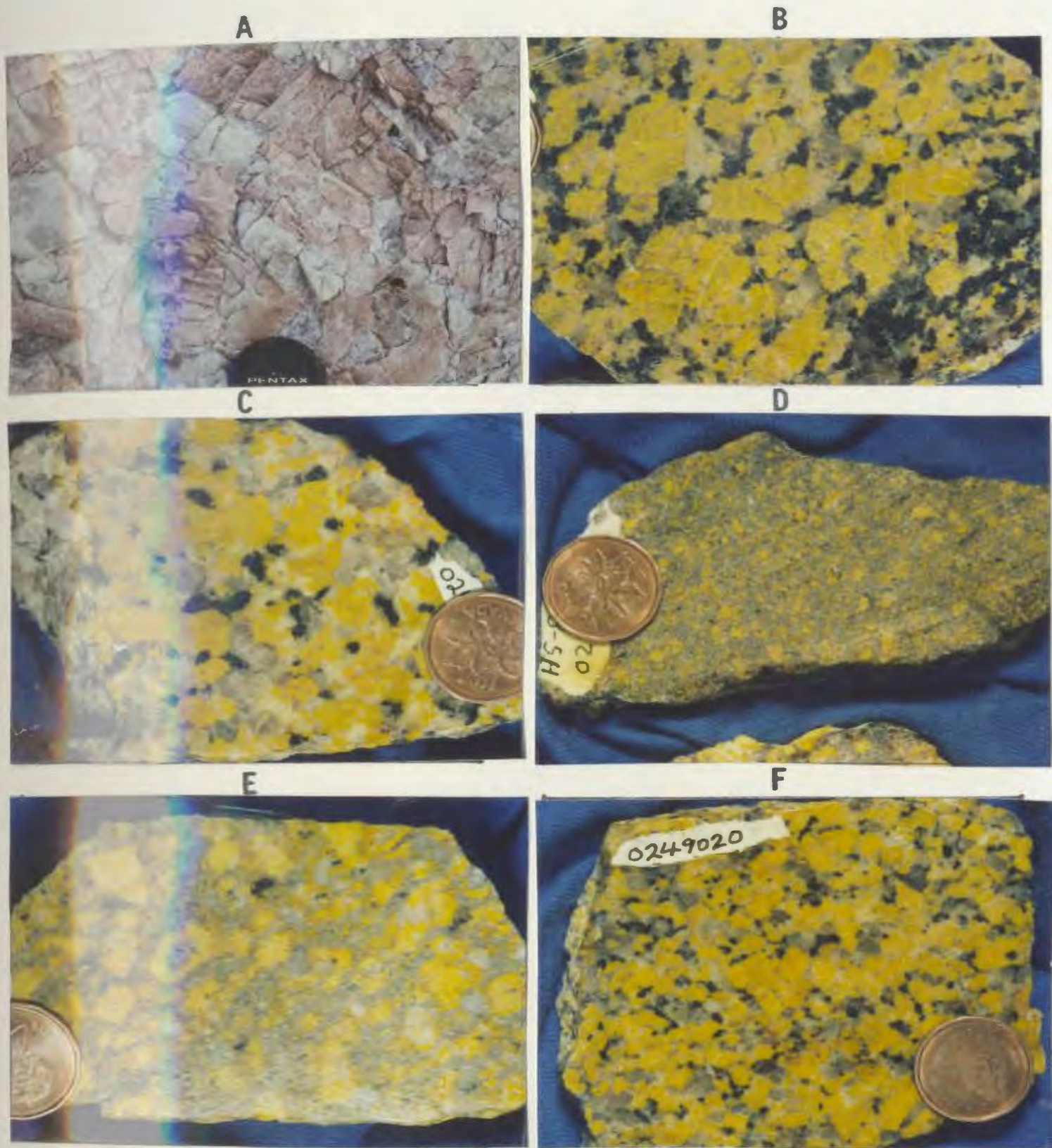
Plate 4.5. Features of the Strawberry Intrusive Suite (see also Plate 4.4). (a) Molbdenite-bearing pegmatite, Ford's Bight. (b) Melanocratic variant of the Bayhead Granite, south of Kaipokok Bay. (c) Typical Cape Strawberry Granite. (d) Fine-grained, reibeckite-bearing, grey phase of Cape Strawberry Granite. (e) Quartz-feldspar porphyry associated with Dog Islands Granite, note oscillatory feldspar zoning. (f) Medium-grained, variably porphyritic Tukialik Granite. Slabs stained for K-feldspar.

of euhedral biotite and hornblende crystals, associated
with euhedral sphene, allanite and zircon. They indicate at
least local fractionation of biotite and accessory
minerals.

Dog Islands Granite

The name Dog Islands Granite is introduced for granites
on Dog Island, Iron Island, Burnt Island, and the adjacent
mainland (Figure 4.1), corresponding to Units 17 and 18 of
Gower (1981). Fluorite-bearing quartz-feldspar porphyry
dykes that resemble the granite cut quartz monzonite of the
Numok Intrusive Suite on nearby islands. This suggests a
maximum age of ca. 1800 Ma; correlation with the Cape
Strawberry Granite suggests an age of ca. 1760 Ma. The Dog
Islands Granite is almost identical to the type area, but
is more homogeneous, and locally quartz-porphyritic (Plate
4.5). Mafic mineral layering occurs at the western end of
Iron Island (see also Gower, 1981), and is interpreted here
as a cumulus feature. A syenite to quartz syenite variant
present in the east of Dog Island and on Burnt Island
(corresponding partly to unit 18 of Gower, 1981) locally
contains distinctive blue poikilitic amphibole (reibeckite
or arfvedsonite). A pleochroic, green, clinopyroxene
(probably aegirine-augite) is present in one sample. Other
mafic phases include green hornblende and biotite,
associated with fluorite, zoned allanite and euhedral
zircon. The mineralogy is very similar to the fine-grained,
marginal, grey phase of the Cape Strawberry Granite (see
above).
Feldspar and quartz-feldspar porphyry dykes assigned to
the Dog Islands granite are mineralogically similar to the
coarse phase. Quartz phenocrysts show rounded and resorbed

outlines. K-feldspar phenocrysts locally contain cores of saussuritized plagioclase and, in one instance, alternating rings of K-feldspar and plagioclase indicate oscillatory growth. Chloritized biotite, fluorite, magnetite and sphene form interstitial clots.

Tukialik Granite

Tukialik Granite is a new name introduced for rocks exposed on Bear Island and in the eastern Benedict Mountains, corresponding to Unit 23 of Gower (1981). It consists dominantly of coarse grained biotite granites similar to those described above.

The unit is in contact with monzonite and syenite of the Mount Benedict Intrusive Suite (see Chapter 5) along its southern boundary; this contact is interpreted to be the continuation of the Adlavik Brook fault zone in the west. The nature of the southern contact in the east is unknown. To the west, the Tukialik Granite may be continuous with the Dog Islands Granite. Bailey (field notes, 1979) suggested that the granite was gradational with metavolcanic rocks east of Tukialik Bay; however, this enclave is locally cut by veins of pink granite.

In comparison to other members of the Strawberry Suite, the Tukialik Granite is richer in K-feldspar, slightly finer-grained, and locally equigranular. Blue quartz is prominent in many samples. A quartz-feldspar porphyry variant occurs locally on Bear Island and resembles similar rock types grouped with the Dog Islands granite. Alteration of biotite to chlorite appears less intense than in the Cape Strawberry or Dog Islands Granites.

4.4.3 Lanceground Intrusive Suite

Definition and Distribution

Lanceground Intrusive Suite is a new name introduced
for three discrete plutons; two of these are located near
Adlavik Bay, and the third is adjacent to the Adlavik Brook
Fault zone (Figure 4.1). All three show similar
characteristics, but the most southerly has been affected
by Grenvillian deformation and metamorphism. There appears
to be a spatial association between these granites and the
Numok Intrusive Suite, although a case could also be made
for a spatial link to the Adlavik Intrusive Suite. A Rb-Sr
isochron from the Lanceground Hills Granite (Chapter 8)
suggests an ambiguous age of 1692 ± 32 Ma, but is probably
disturbed, as it has a very low initial ratio. U-Pb zircon
geochronology is in progress as of thesis submission. The
Lanceground Suite shows a strong geochemical affinity to
other known members of the post-tectonic Makkovikian
association (see section 4.2).

Lanceground Hills and Pistol Lake Granites

The Lanceground Hills Granite corresponds to part of
unit 26c of Gower et al.(1982), and the Pistol Lake Granite
to part of their unit 28a (Monkey Hill Granite). The two
units are, however, closely similar, and both consist
dominantly of coarse grained, K-feldspar porphyritic,
locally hypersolvus, biotite-hornblende syenite, quartz
syenite, granite and alkali-feldspar granite (Table 4.1;
Plate 4.6).

Field Relations : Contact zones of the Lanceground
Hills Granite coincide with the agmatite zone at the

western margin of the Numok Intrusive Suite. A dyke of brown-weathering, hypersolvus, quartz syenite (typical of the suite) cuts the foliated agmatite, indicating that emplacement of the granite post-dated the leucosome (dated at ca. 1800 Ma, see above) and also deformation (unconstrained). The relationship between the Lanceground Hills Granite and adjacent gabbro-diorite of the Adlavik Intrusive Suite is unknown. The Pistol Lake Granite is in contact with the Upper Aillik Group for 10 km, but most of the contact is obscured by drift. The granite intrudes the Aillik Group in two localities, and is locally intruded by biotite-bearing gabbro that resembles parts of the Adlavik Suite.

Both units are generally fresh and massive, although the western part of the Lanceground Hills granite locally displays a moderate northeast to east-trending foliation. Syenitic variants resemble equivalent rocks of the Numok Suite (see above), and parts of the Lanceground Hills Granite show the same intense weathering to yellow gravel.

Petrographic Characteristics : Both units include rocks that show hypersolvus characteristics, and virtually all contain euhedral to rounded phenocrysts of very coarse microcline-perthite, locally displaying relict simple twinning suggesting original orthoclase or sanidine crystals. Free plagioclase (where present) is confined to the groundmass, although it locally forms isolated phenocrysts mantled by K-feldspar.

Red-brown biotite is the most common mafic mineral, and in relatively melanocratic variants, is accompanied by variably poikilitic blue-green hornblende. A few samples also contain small amounts of an intense blue arfvedsonite or reibeckite amphibole. A green, pleochroic clinopyroxene
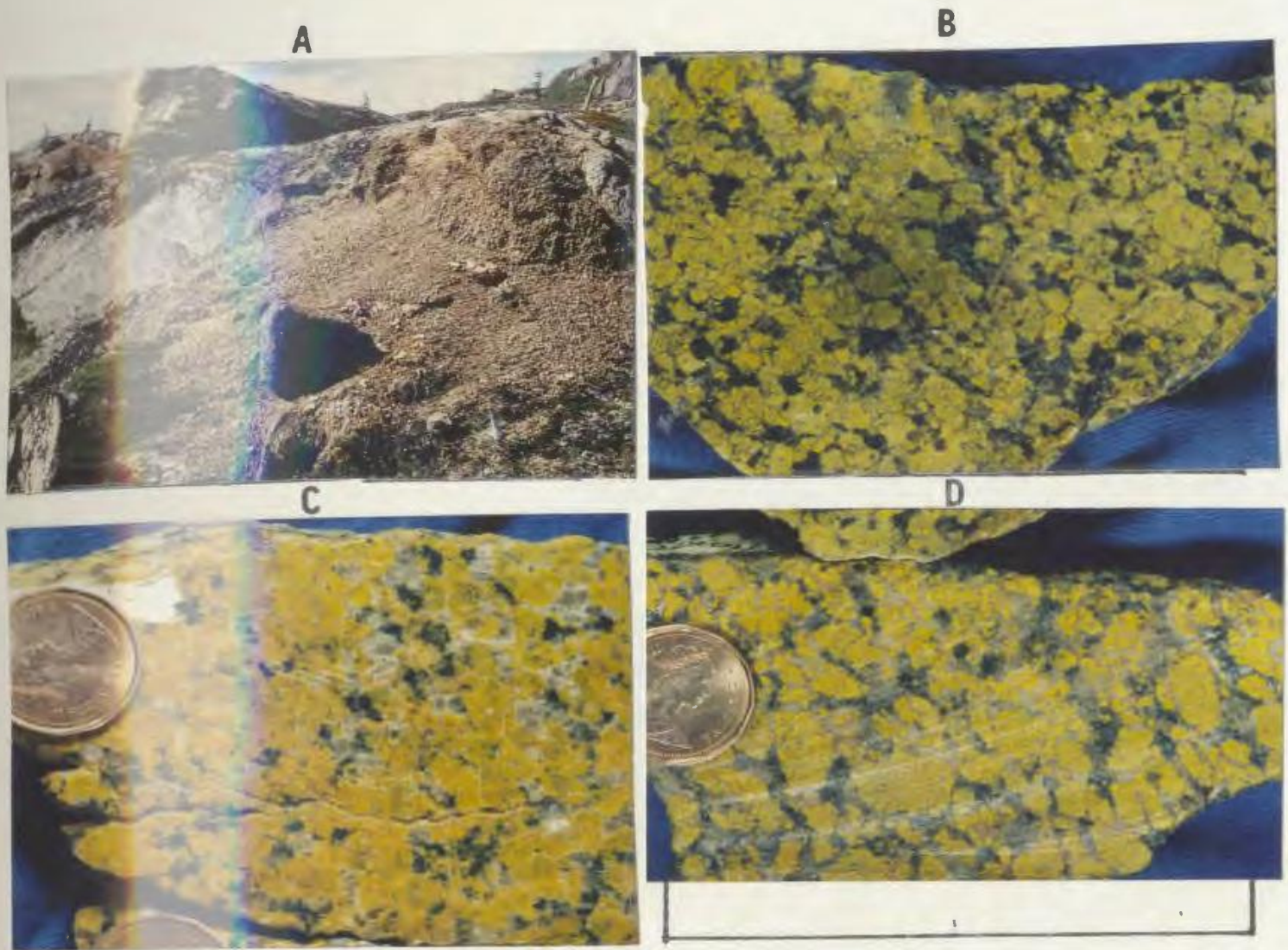
Plate 4.6. Features of the Lanceground Intrusive Suite. (a) Intense
    weathering of the Lanceground Hills Granite, near Adlavik Bay,
    probably indicating the former presence of fayalite. (b) Hypersolvus
    syenite, Adlavik Bay. Note coarse perthite, and similarity to Numok
    Suite syenites (Plate 4.2). (c) Alkali-feldspar quartz syenite of the
    Pistol Lake Granite, south of Bernard Lake. (d) Coarse-grained,
    deformed alkali-feldspar granite from the Tarun Granite, near White
    Bear Mountain. Slabs stained for K-feldspar.

that locally occurs as relict grains within hornblende is probably aegirine-augite. Amorphous iron-oxide - hydroxide clots locally contain relict fayalitic olivine. Minor phases include prominent interstitial fluorite, prominent allanite (intergrown with mafic silicates), apatite, sphene, and euhedral zircon crystals up to 2 mm in length.

Tarun Granite

The Tarun Granite is located near the Benedict fault zone, and around White Bear Mountain. It corresponds to part of Unit 26c of Gower et al (1982). Original igneous textures and mineralogy have been obliterated by recrystallization in many samples. Well-preserved examples are pink or buff, coarse grained, K-feldspar porphyritic granites that resemble those from the type area; there is also a strong geochemical similarity (see 4.2).

Contact relationships of the Tarun Granite are poorly known. The northern limit is difficult to place as there is little contrast between the granite and syenite-quartz syenite of the Numok Suite. The most likely position coincides with the projected trace of a fault indicated by Gower et al.(1982); alternatively, the two might be gradational.

The Tarun granite is spatially associated with quartz-feldspar porphyry (assigned to the Upper Aillik Group; see Chapter 7) that forms the main peak of White Bear Mountain. The northern contact of the porphyry unit (from Gower et al., 1982) is approximately coincident with the 1200-1400 feet (400-475 m) contour interval, and follows the topography . It is suggested that this contact has a shallow inclination, and that the Tarun granite is

continuous beneath the peak. The nature of the granite - porphyry contact is unknown, but there is a strong compositional similarity between them (Chapter 7) that may indicate a genetic link.

4.1.4 Big River Granite

This is a new name proposed for an extensive granitoid unit in the southeast of the study area (Figure 4.1). It corresponds to unit 26b and part of unit 23 of Gower et al. (1982). It is dominated by pink to red or white, coarse grained, K-feldspar porphyritic, leucocratic, hornblende-biotite granite and alkali-feldspar granite, locally ranging in composition to quartz monzonite and quartz syenite (Table 4.1; Plate 4.7). Textural variants include a dominant porphyritic granitoid, and a subordinate equigranular phase. The former is characterized by mantled plagioclase phenocrysts with K-feldspar rims for which the term "pseudorapakivi texture" is used here (classical rapakivi or "wiborgite" textures consist of albite on orthoclase; e.g. Vorma, 1976).

Field Relationships : The western boundary of the unit coincides with an inferred fault zone that links the Benedict and Adlavik Brook fault zones, marked by a prominent linear escarpment. The southern boundary corresponds with the Benedict Fault system. The nature of the poorly-exposed eastern boundary is unclear; a foliated grey dioritic granitoid in this area is atypical of most of the unit, and may represent a screen of older material between it and adjacent units.
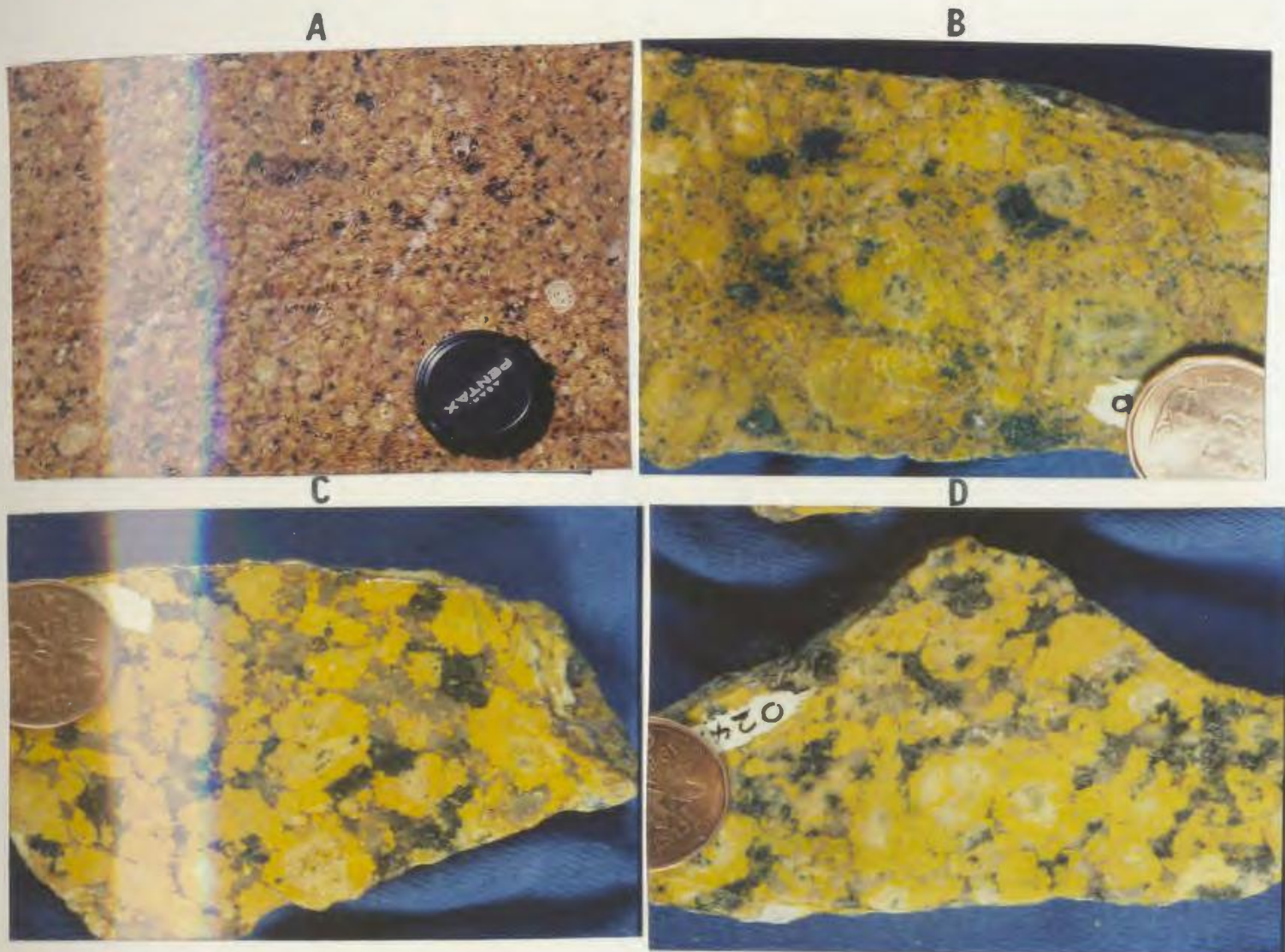
Plate 4.7. Features of the Big River Granite. (a) Red-weathering pseudorapakivi granite, south of the estuary of Big River, note ovoidal phenocrysts. (b) Fine-grained, porphyritic phase, with feldspar zoning partly defined by mafic inclusion trails, near Big River. (c) and (d) Typical coarse-grained pseudorapakivi granites, from the escarpment east of Big River Valley. Slabs stained for K-feldspar.

Geochronology : A Rb-Sr isochron from the dominant porphyritic granite (Chapter 8) yields an age of 1793 ± 28 Ma, and shows no evidence of disturbance.

Lithology and Petrography : Pseudorapakivi texture is variably developed, but is present in at least vestigial form in most porphyritic variants. Massive, undeformed variants dominate the northern part of the unit, but variably foliated and/or cataclastic rocks occur in the south. Foliations have a general east-west trend, but are locally variable. The transition from foliated to massive granite appears to be gradational, and the cataclastic rocks probably form local zones of high strain parallel to the Benedict Fault zone. Medium-grained equigranular variants occur mostly in the southeast and northwest of the unit. They are more siliceous than the porphyritic phase and have a higher biotite/hornblende ratio.

Hornblende in this unit is a deep green or blue-green variety. Pale green, locally faintly pleochroic clinopyroxene (possibly aegirine-augite) is present rarely as a relict phase, altered to amphibole and/or biotite. Gower (1981) also reports reibeckite in two such samples from the unit, but this mineral does not appear to be widespread in the unit. Sphene is a prominent minor phase (up to 1% in some samples), and is commonly euhedral. Other accessory phases are prominent, but not as abundant as in the Strawberry and Lanceground Suites. Composite phenocrysts commonly have zoned, variably saussuritized plagioclase cores, surrounded by perthitic microcline. In most cases, there is a single mantle only; oscillating zones of plagioclase and K-feldspar are very rare.

4.2 DESCRIPTIVE GEOCHEMISTRY

Post-tectonic Makkovikian plutonic rocks are
represented by 460 samples; 264 of these are regional
samples collected on a 2 km random grid spacing. The
remainder include 114 follow-up samples, collected from
granites of the Strawberry and Lanceground Intrusive
Suites, and 82 geological samples distributed approximately
equally amongst all units. Characteristics of and usage of
sample populations are explained in Chapter 1.

4.2.1 General Geochemistry

Summary of Numerical Data

Average major element, trace element and partial CIPW
normative compositions of post-tectonic Makkovikian units
are listed in Table 4.2. The Numok Intrusive Suite is
characterized by lower SiO_2 (60-65%) than other units,
and is discussed separately from remaining units, which are
referred to below collectively as "siliceous granitoids".

Numok Intrusive Suite : The plagiophyric monzodiorite
and monzonite unit has the least differentiated
composition. There are significant compositional
differences between the quartz monzonite unit in northern
and southern zones; in the south it has lower SiO_2, and
is closer in composition to the plagiophyric monzonite unit
than to the syenite unit. In contrast, the quartz monzonite
and quartz syenite units of the northern zone are similar
in composition, although the latter is richer in K_2O.

Table 4.2 . Average compositions of post-tectonic Makkovikian plutonic rocks, subdivided by principal units.

UNIT	20.1		20.2		21.1		21.2		22.2		23.0		24.1		24.2	
n1	42		15		18		22		10		57		42		7	
n2	10		2		4		2		3		35		38		6	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	64.98	4.21	59.64	4.32	64.31	5.04	66.73	2.80	57.60	2.33	69.78	5.20	72.85	3.56	70.59	3.83
TiO2	0.73	0.35	0.83	0.23	0.72	0.40	0.54	0.17	0.91	0.21	0.43	0.35	0.21	0.11	0.26	0.09
Al2O3	15.62	1.28	17.76	1.70	15.35	1.41	14.79	1.00	17.87	0.77	13.94	1.27	12.99	1.42	14.54	1.71
Fe2O3	1.43	0.67	2.00	0.82	1.40	0.74	1.47	0.47	2.10	0.39	1.05	0.75	1.14	0.80	1.14	0.59
FeO	3.22	1.24	3.60	0.99	4.07	2.14	3.24	1.36	4.45	1.02	2.37	1.47	1.34	0.82	1.37	0.56
MnO	0.13	0.06	0.10	0.03	0.17	0.09	0.13	0.05	0.11	0.02	0.07	0.05	0.06	0.06	0.07	0.06
MgO	0.72	0.54	1.71	1.20	0.49	0.43	0.31	0.14	2.35	0.62	0.51	0.61	0.29	0.62	0.28	0.14
CaO	2.05	0.92	3.78	1.68	1.90	0.88	1.61	0.54	5.02	1.09	1.49	1.08	0.96	1.33	0.95	0.21
Na2O	4.68	0.53	4.45	0.29	4.56	0.77	4.46	0.37	4.44	0.73	3.95	0.71	4.16	1.26	4.18	0.57
K2O	5.35	0.77	4.92	1.40	5.93	0.86	5.68	0.47	4.01	0.57	5.07	1.04	4.92	1.15	5.76	1.16
P2O5	0.21	0.17	0.27	0.11	0.20	0.19	0.10	0.06	0.32	0.08	0.10	0.11	0.03	0.03	0.07	0.04
LOI	0.50	0.21	0.65	0.48	0.49	0.27	0.42	0.19	0.76	0.42	0.59	0.19	0.62	0.35	0.56	0.12
TOTAL	99.62		99.71		99.59		99.48		99.94		99.35		99.57		99.77	

(ppm) Trace Elements

	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Li	20.0	12.3	22.1	7.1	14.7	9.8	11.3	5.5	18.5	4.9	22.5	18.7	29.7	26.2	20.6	6.5
F	732.0	404.6	1125.7	468.1	465.6	312.3	390.1	228.4	696.9	370.5	922.9	723.5	1669.0	942.8	893.9	558.7
Sc	10.5	3.5	10.5	0.7	14.9	7.1	7.0	0.6	10.8	3.9	4.6	4.3	1.6	1.5	3.9	1.8
V	33.5	25.2	78.2	49.7	20.1	11.9	15.4	8.0	103.6	29.7	28.9	30.4	22.2	47.7	14.4	9.1
Cr	3.1	3.9	10.9	16.0	2.0	1.2	4.8	3.5	22.1	9.1	4.7	4.8	5.8	7.4	8.4	12.7
Ni	1.3	0.5	6.1	8.8	1.0	0.0	1.2	1.1	11.8	4.1	2.1	3.5	2.6	6.6	1.9	1.6
Cu	6.7	3.6	20.5	15.5	7.5	4.5	5.3	1.7	34.6	9.1	4.6	4.1	13.2	51.2	5.3	3.6
Zn	93.5	26.2	79.1	20.7	107.9	42.4	120.7	46.0	79.4	13.7	74.0	38.8	84.7	70.5	115.7	149.5
Ga	20.2	3.6	20.7	2.3	20.8	2.6	22.5	10.0	19.7	2.3	17.4	7.0	17.1	7.3	18.4	6.1
Rb	102.4	42.3	141.3	53.4	94.8	55.9	126.8	53.0	109.5	31.2	151.7	63.6	181.7	64.0	170.3	33.3
Sr	204.8	132.2	453.9	201.0	114.9	75.1	102.1	79.0	512.1	103.2	119.4	110.4	66.5	67.0	113.6	73.5
Y	39.6	12.9	38.8	14.2	33.4	15.5	73.6	24.2	34.0	4.5	57.1	37.3	66.8	48.2	46.7	6.6
Zr	460.1	260.2	564.6	233.9	577.8	446.6	951.0	328.7	352.6	236.5	467.8	399.5	447.2	314.1	454.6	166.0
Nb	18.0	7.2	20.3	9.8	15.3	5.3	27.3	8.5	15.7	3.6	25.7	13.2	30.8	36.3	21.4	2.2
Mo	3.9	1.1	4.3	0.8	2.9	0.9	3.9	1.3	4.1	1.0	4.3	1.8	3.9	2.2	3.3	1.4
Sn	2.4	2.5	3.0	2.8	1.5	1.0	1.0	0.0	2.3	1.5	4.0	2.9	5.3	3.3	3.7	3.0
Cs	1.9	2.3	1.3	1.1	0.9	0.8	0.5	0.0	1.5	0.9	1.2	1.1	1.1	0.7	1.4	1.1
Ba	1134.0	804.3	1063.9	311.6	743.2	656.5	832.2	427.6	860.3	166.7	706.4	479.6	327.7	266.4	504.0	220.6
La	73.4	46.3	56.2	17.2	60.9	28.6	93.4	24.3	53.8	6.5	101.5	108.0	78.0	43.8	105.3	46.9
Ce	144.2	87.0	117.7	39.5	115.9	56.8	196.8	52.6	104.5	18.0	198.5	199.2	161.7	81.5	196.3	83.1
Sm	11.5	4.8	15.0	1.4	11.5	1.3	17.5	6.4	8.8	0.7	13.1	7.3	12.9	6.7	14.2	4.5
Yb	3.3	1.7	4.3	2.5	2.5	0.0	8.0	0.0	2.5	0.0	5.3	2.2	8.2	5.5	5.3	2.2
Hf	8.7	5.5	15.0	1.4	11.5	7.1	17.0	2.8	7.7	1.2	11.0	6.5	13.6	8.1	13.3	4.0
Pb	16.3	6.9	15.5	6.3	14.5	6.8	17.1	7.4	13.2	3.7	23.6	7.9	22.5	9.8	26.9	9.5
Th	6.7	6.9	11.5	14.5	1.8	2.5	8.4	7.2	7.4	4.4	17.0	16.4	27.0	31.3	14.0	8.1
U	3.2	1.9	3.1	1.5	1.8	1.5	3.1	1.4	3.6	1.6	4.5	3.8	8.0	11.3	4.7	1.0

(Wt%) Partial CIPW norms

	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Q	11.33	8.12	4.70	4.67	7.14	9.46	14.40	6.02	2.40	2.11	23.06	9.88	27.54	8.62	21.90	10.29
C	0.00	0.00	0.09	0.35	0.03	0.09	0.00	0.00	0.00	0.00	0.16	0.28	0.04	0.11	0.18	0.21
Or	31.90	4.54	31.03	5.07	31.19	7.99	33.84	2.79	23.86	3.36	30.30	6.19	29.36	6.81	34.26	6.93
Ab	39.95	4.43	37.96	2.52	42.45	8.60	38.11	3.11	37.68	5.85	33.79	6.08	35.17	10.88	35.25	4.03
An	5.84	3.12	12.89	5.84	6.97	5.74	3.58	1.81	17.11	3.99	5.00	2.93	2.33	1.66	3.46	1.57
Di	2.86	1.57	2.84	1.39	3.62	2.71	3.41	1.78	5.12	1.70	1.65	2.36	1.57	4.86	0.40	0.85
Hy	4.14	2.01	4.91	2.50	3.22	2.54	3.22	1.61	7.03	3.99	3.39	2.15	1.48	1.39	1.80	0.98
Ol	0.01	0.08	0.80	2.09	1.21	2.72	0.00	0.00	1.12	2.37	0.02	0.13	0.00	0.03	0.00	0.00
Mt	2.09	0.97	2.72	0.94	2.15	0.94	1.96	0.62	3.06	0.58	1.51	1.04	1.25	0.90	1.66	0.87
Il	1.40	0.68	1.56	0.44	1.38	0.66	1.04	0.32	1.73	0.40	0.83	0.64	0.41	0.22	0.50	0.17

KEY TO UNITS (MIS - Mumok Intrusive Suite. SIS - Strawberry Intrusive Suite)
20.1 -- (MIS) Monzonite to Quartz Monzonite (Northern Zone)
20.2 -- (MIS) Monzonite to Quartz Monzonite (Southern Zone)
21.1 -- (MIS) Syenite to Quartz Syenite (Northern Zone)
21.2 -- (MIS) Syenite to Quartz Syenite (Southern Zone)
22.2 -- (MIS) Plagiophyric Monzodiorite and Monzonite
23.0 -- (SIS) Bayhead Granite
24.1 -- (SIS) Cape Strawberry Granite
24.2 -- (SIS) October Harbour Granite
n1 -- number of analyses for all elements except those listed below
n2 -- number of analyses for Sc, Sn, Cs, Sm, Yb and Hf

Table 4.2 (continued).

UNIT	24.3		25.0		26.0		27.0		28.0		29.0		30.1		30.2	
n1	4		33		50		22		19		41		64		15	
n2	3		31		29		20		15		31		13		0	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO_2	74.58	0.83	70.80	5.02	71.99	4.15	72.50	2.01	70.12	3.39	72.84	2.75	69.00	5.09	74.81	1.47
TiO_2	0.14	0.04	0.32	0.36	0.28	0.15	0.26	0.07	0.44	0.32	0.30	0.11	0.44	0.21	0.16	0.08
Al_2O_3	13.14	1.39	13.91	1.40	13.64	1.76	13.16	0.77	13.76	1.72	12.99	1.34	14.75	1.77	13.09	0.65
Fe_2O_3	1.43	1.28	0.95	0.94	1.00	0.51	1.10	0.50	1.65	0.74	1.07	0.39	1.25	0.57	0.78	0.18
FeO	0.34	0.23	1.92	2.37	1.20	0.80	1.30	0.56	1.79	1.35	1.35	0.68	1.72	0.93	0.49	0.26
MnO	0.03	0.01	0.06	0.08	0.05	0.04	0.05	0.02	0.09	0.05	0.06	0.03	0.07	0.04	0.04	0.02
MgO	0.11	0.06	0.26	0.36	0.31	0.27	0.17	0.21	0.23	0.15	0.17	0.15	0.59	0.91	0.13	0.11
CaO	0.51	0.34	1.06	0.81	0.95	0.73	0.77	0.38	1.14	0.60	0.82	0.42	1.56	1.25	0.53	0.30
Na_2O	3.52	0.50	4.08	0.48	4.11	0.68	3.95	0.43	4.09	0.68	3.92	0.66	4.21	0.72	4.59	0.84
K_2O	5.76	0.60	5.41	1.25	5.15	0.69	5.58	0.41	5.46	1.57	5.42	0.67	5.25	0.92	4.47	1.18
P_2O_5	0.01	0.01	0.07	0.11	0.06	0.08	0.04	0.03	0.07	0.07	0.04	0.02	0.11	0.07	0.03	0.03
LOI	1.44	1.97	0.62	0.18	0.79	0.26	0.56	0.11	0.56	0.30	0.50	0.18	0.61	0.31	0.49	0.12
TOTAL	101.01		99.46		99.53		99.44		99.40		99.48		99.56		99.61	
(ppm)																
Li	11.0	6.5	31.2	30.3	22.7	23.3	15.6	7.2	10.3	4.9	14.6	15.2	15.4	6.1	12.1	6.0
F	623.5	1106	1868.1	1455	1592.0	1256	1804.5	1069	941.4	879.6	1084.7	763.1	590.7	387.9	1105.4	533.5
Sc	0.6	0.2	4.0	6.6	2.5	1.6	2.5	1.7	7.0	10.2	3.2	1.7	2.4	0.9		
V	19.3	1.7	18.8	11.1	21.2	13.3	10.6	8.9	13.3	6.9	13.8	7.4	24.1	17.7	10.1	5.8
Cr	5.5	2.7	1.9	1.2	6.3	7.8	3.3	2.3	4.1	2.8	3.8	3.3	4.8	14.9	4.7	7.0
Ni	2.0	1.4	1.1	0.4	2.3	2.8	1.3	0.9	1.1	0.3	1.8	2.4	2.2	8.0	4.1	7.5
Cu	5.8	3.9	16.1	72.9	6.5	5.4	5.7	3.5	9.0	18.1	4.7	3.5	7.0	6.5	3.1	1.6
Zn	60.0	52.2	82.0	107.1	61.7	48.7	87.9	53.6	106.1	67.2	82.8	59.0	63.6	42.5	17.3	14.8
Ga	8.3	2.5	22.1	8.1	12.1	6.5	27.1	9.2	26.0	10.6	16.2	7.3	16.1	4.9	11.1	4.5
Rb	169.0	34.1	200.6	73.6	198.8	52.6	186.5	29.2	168.1	35.9	167.1	52.5	123.8	53.3	144.6	42.5
Sr	151.5	84.9	94.5	64.5	139.8	190.9	54.6	57.8	71.3	69.9	60.0	68.8	179.3	154.7	81.3	110.0
Y	37.3	21.2	60.2	65.3	41.4	23.3	69.6	36.3	77.6	36.8	75.5	29.3	44.8	17.7	32.4	10.3
Zr	325.5	246.4	573.5	803.3	465.9	637.0	776.0	707.5	691.7	330.0	560.7	280.9	409.4	213.0	195.9	50.0
Nb	18.0	6.5	26.7	18.3	22.2	8.7	28.6	10.9	30.4	13.8	29.2	10.1	18.4	7.3	22.3	6.2
Mo	2.8	0.5	6.3	18.4	3.6	2.6	5.1	2.9	4.8	2.8	3.6	1.5	3.7	1.2	3.4	1.5
Sn	3.3	0.6	10.0	20.4	5.1	2.7	3.7	2.3	4.1	2.7	4.2	2.8	2.7	2.7		
Cs	1.1	0.5	0.7	0.5	1.7	1.5	1.1	0.7	1.1	0.6	1.1	0.7	0.7	0.6		
Ba	396.0	247.0	448.2	192.2	456.4	360.0	274.5	222.0	440.0	311.4	308.1	244.0	762.3	465.6	227.7	272.3
La	29.8	29.1	137.6	214.3	65.3	40.5	147.6	73.6	133.0	82.1	104.7	36.4	67.2	29.8	45.9	26.1
Ce	76.5	63.7	249.1	367.9	134.7	80.6	293.2	145.2	270.3	155.0	211.9	71.6	134.6	59.2	93.6	47.7
Sm	8.1	5.4	16.1	18.7	10.3	4.6	21.5	10.0	25.8	13.1	18.0	6.6	10.4	3.9		
Yb	4.8	2.3	7.1	6.9	6.0	2.5	7.8	4.7	10.5	5.7	8.5	2.9	4.2	2.0		
Hf	9.8	6.2	17.1	25.1	12.1	6.2	20.1	13.4	22.6	11.0	16.8	7.0	10.1	3.0		
Pb	26.8	3.6	113.6	500.5	18.8	10.2	23.6	11.0	25.0	18.9	24.7	12.0	19.4	11.5	10.1	4.6
Th	6.8	1.7	20.7	22.8	12.8	9.3	16.4	7.4	14.3	7.0	22.3	7.3	13.0	10.2	13.1	6.5
U	3.0	0.7	5.4	3.3	5.3	2.8	5.2	2.0	4.1	1.6	6.3	2.4	4.2	2.7	5.9	2.0
(Wt%)																
Q	30.86	4.00	23.27	8.74	26.17	8.48	26.46	4.40	23.17	10.42	27.49	7.01	20.30	10.05	30.06	2.46
C	0.19	0.16	0.06	0.12	0.16	0.28	0.03	0.09	0.35	1.45	0.01	0.05	0.07	0.15	0.02	0.07
Or	34.17	3.56	31.23	3.82	30.83	4.12	33.33	2.43	32.53	9.25	32.33	3.97	31.35	5.43	26.65	7.01
Ab	29.87	4.30	35.21	3.75	35.09	5.63	33.64	3.65	34.66	5.96	33.46	5.51	35.93	6.02	39.13	7.19
An	2.53	1.82	3.63	1.93	3.21	3.18	1.70	1.58	2.26	1.88	1.84	1.57	5.69	4.27	1.88	1.67
Di	0.00	0.00	1.18	2.03	0.88	1.38	1.51	1.34	1.98	1.71	1.50	1.17	1.28	1.80	0.40	0.24
Hy	0.36	0.26	2.34	3.54	1.35	1.17	0.85	0.89	1.16	1.50	0.92	0.89	2.16	1.22	0.29	0.52
Ol	0.00	0.00	0.07	0.38	0.06	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.22	1.78	0.00	0.00
Mt	0.71	0.52	1.40	1.40	1.35	0.73	1.53	0.77	2.03	1.00	1.50	0.57	1.74	0.84	0.97	0.34
Il	0.21	0.04	0.64	0.73	0.53	0.28	0.50	0.14	0.85	0.62	0.57	0.20	0.84	0.41	0.31	0.16

KEY TO UNITS (LIS - Lanceground Intrusive Suite. SIS - Strawberry Intrusive Suite.)
24.3 (SIS) Poodle Pond Granite
25.0 (SIS) Dog Islands Granite
26.0 (SIS) Tukialik Granite
27.0 (LIS) Lanceground Hills Granite
28.0 (LIS) Pistol Lake Granite
29.0 (LIS) Tarun Granite
30.1 Big River Granite (porphyritic phase)
30.2 Big River Granite (equigranular phase)
n1 -- number of analyses for all elements except those listed below
n2 -- number of analyses for Sc, Sn, Cs, Sm, Yb and Hf

Trace element patterns are also similar, except for lower F, Sr and Ba in the syenite unit. This similarity is consistent with apparent gradational contacts between them in this area.

Siliceous Granitoid Units : Contrasts in geochemistry amongst these units are subtle. The Lanceground Intrusive Suite has slightly higher mean K_2O, and lower mean Al_2O_3 and MgO than other granitoid units. The Bayhead granite has the least evolved and most variable major element composition in the Strawberry Suite; the Cape Strawberry and Poodle Pond Granites have the most evolved compositions. In the Lanceground Suite, the Pistol Lake Granite has the least evolved composition.

Trace element patterns in the Strawberry and Lanceground Intrusive Suites are similar, but there are small but consistent differences between them. Fluorine contents tend to be higher in the Strawberry Suite, as do Li, Sr and Ba. The Lanceground Suite shows generally higher levels of Zr, La, Ce, Y and other REE. Note that the high Pb content of the Dog Islands granite is a reflection of a single anomalous sample; if this is excluded, it is similar to other members of the suite.

The Big River Granite is similar to all of the above in major element compostion, but has higher Ba and Sr, and lower F, Zn, Rb, Nb, La, Ce, Th and Y contents. Trace element abundances in the main phase of the Big River Granite are similar to those of the Numok Intrusive Suite although the latter has a much less evolved major element composition. The equigranular phase of the Big River Granite is more siliceous than the main phase, and has lower Ba and Sr, but shows similar levels for most other trace elements.
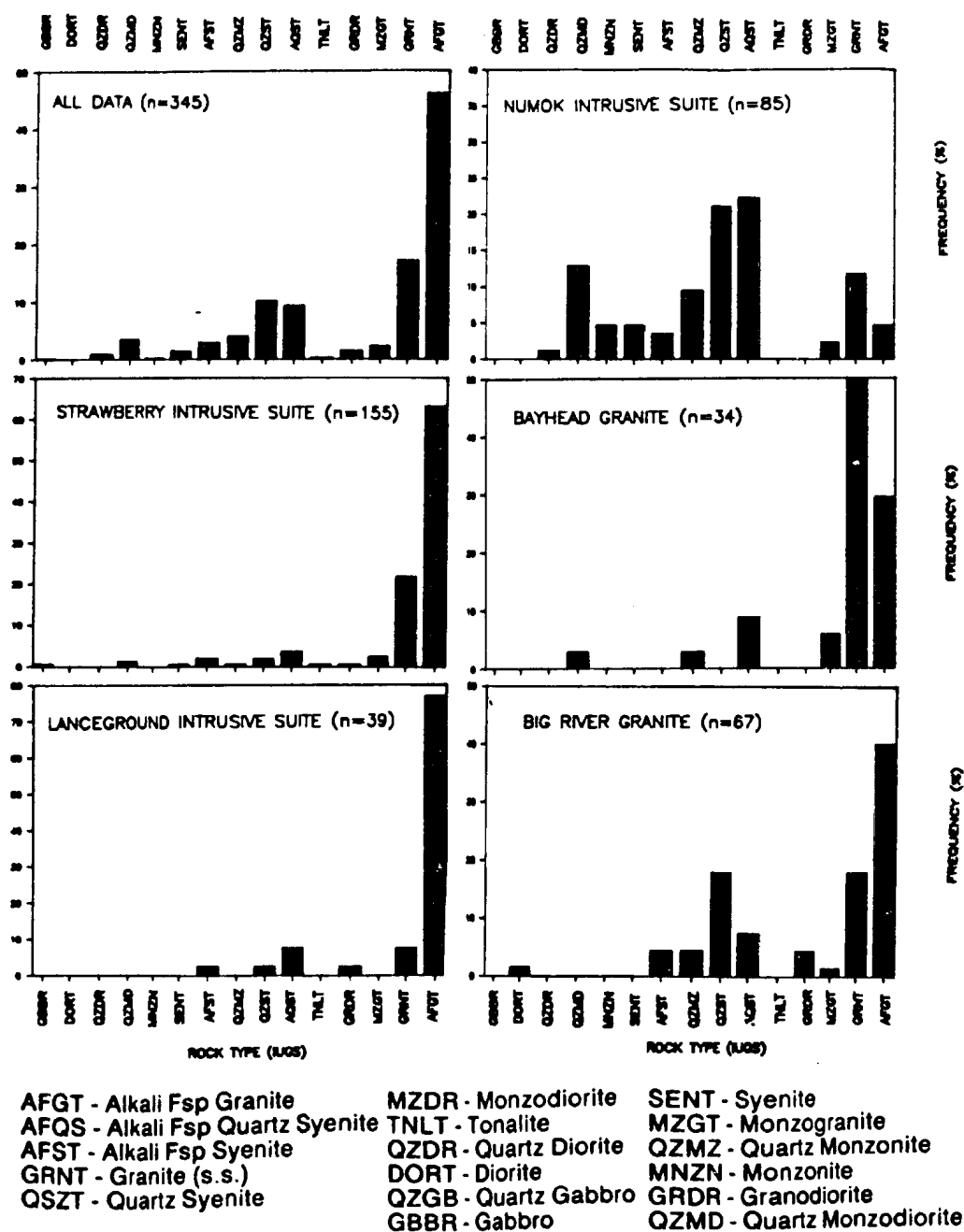
Figure 4.2 . Relative abundance of IUGS rock types calculated from normative mineralogy using the method of Streckeisen and LeMaitre (1979). Note that this is based on Barth mesonorms, not the CIPW norms listed in Table 4.2. Regional and geological sample populations only.

Abundance and Distribution of Rock Types

Relative abundances of IUGS rock types calculated from normative data (regional and geological samples only, after Streckeisen and LeMaitre, 1979) show that post-tectonic Makkovikian rocks are dominated by alkali-feldspar granite and granite, with lesser quartz monzonite and quartz syenite (Figure 4.2). The general distribution resembles that of their syn-tectonic counterparts (Figure 3.2, p.74). The Numok Intrusive Suite is dominated by quartz monzonite, quartz syenite and alkali-feldspar quartz syenite. Siliceous granitoid units are dominated by alkali-feldspar granite and lesser granite (s.s). Alkali-feldspar granite is most abundant in the Lanceground Suite (ca. 80% of total). Within the Strawberry Suite, only the Bayhead Granite is dominated by granite (s.s); all other units are dominated by alkali-feldspar granite (up to 60% of total).

4.2.2 Geochemical Trends and Contrasts

Post-tectonic Makkovikian plutonic rocks are divided into three groups (A, B and C), represented by separate columns of diagrams in Figures 4.3 to 4.10. These subdivisions are intended primarily to reduce "clutter"; they do not necessarily imply genetic links between units.

Note that variation diagrams using SiO_2 as the X-axis employ a different horizontal scale for the Numok Suite, as it has a greater SiO_2 range. Y-axis scales are constant for all figure groups.

Major Element Patterns

Major element trends against SiO_2 show expected patterns, and do not discriminate between units well. The

Figure 4.3 . Variation of selected major elements and derived ratios in post-tectonic Makkovikian plutonic units. See text for discussion.
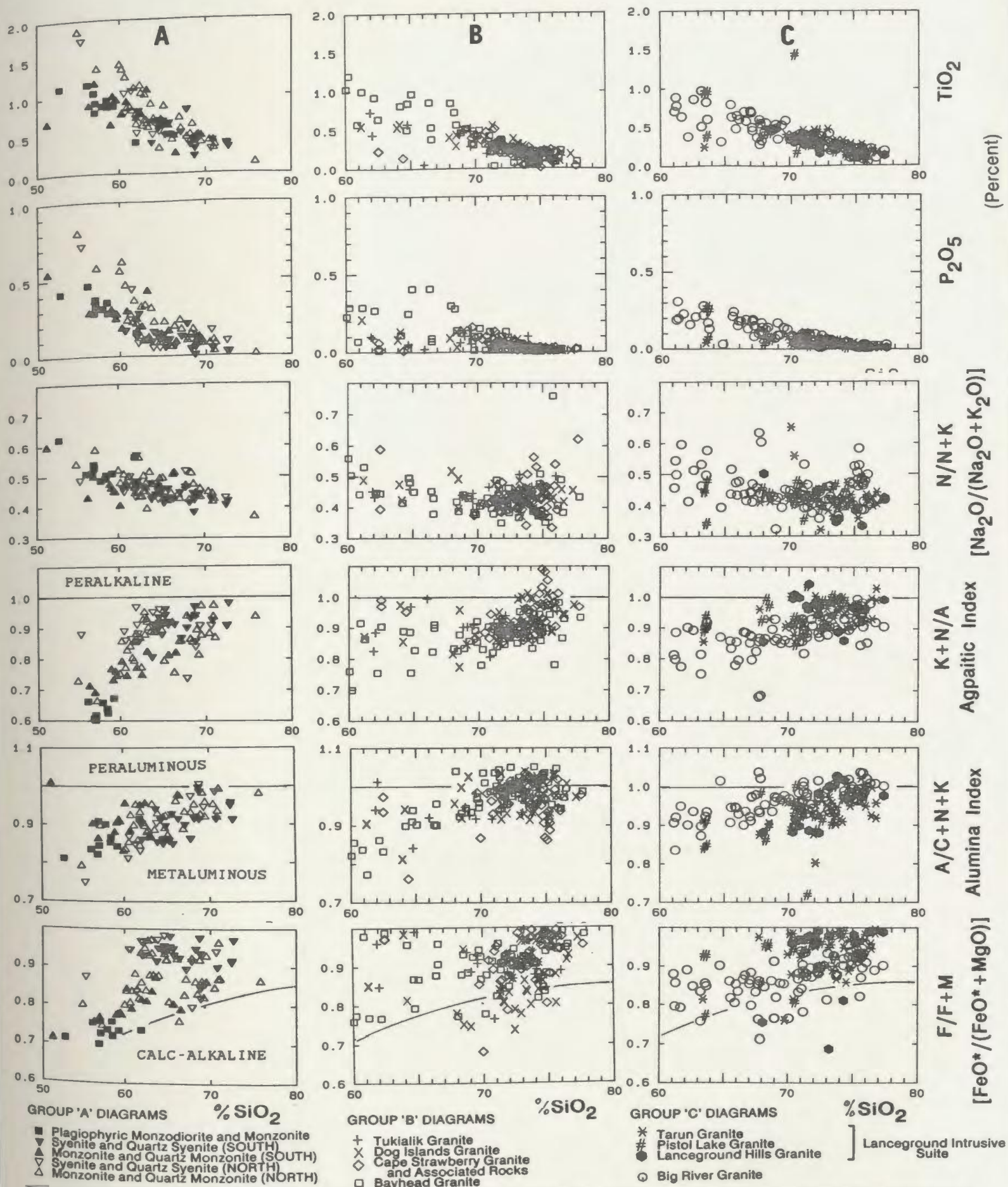
Numok Suite is dominated by rocks with < 65 % SiO_2; these have the highest levels of other major elements except Na_2O and K_2O (see Table 4.2). Amongst the siliceous granitoid rocks, the Big River Granite and Bayhead Granite show the greatest range of major element compositions. Other units within the Strawberry Suite, and the Lanceground Suite, have restricted SiO_2 ranges (70-77%).

TiO$_2$ and P_2O_5 (Figure 4.3) define separate trends for the northern and southern zones of the Numok Suite that coalesce at ca. 65% silica; the northern zone is enriched in both. N/N+K [$Na_2O/(Na_2O + K_2O)$] ratios (Figure 4.3) show a pronounced negative trend against SiO_2 in the Numok Suite, indicating relative enrichment of K_2O with differentiation, but are approximately constant in other units. N/N+K is almost invariably $\leq$ 0.5 above 70% SiO_2, except in a few Na-enriched samples from the Strawberry Intrusive Suite.

K+N/A (agpaitic index) values are generally > 0.95, and both the Strawberry and Lanceground Suites are locally peralkaline. A/C+N+K ratios increase smoothly with SiO_2 (reflecting decreasing Ca for the most part), and parts of the Strawberry Suite (notably the Bayhead Granite) are weakly peraluminous. No units are dominated by peraluminous rocks. All units show high F/F+M (generally $\geq$ 0.85), with the exception of parts of the Numok Suite. They lie above the calc-alkaline field indicated by Anderson (1983), and are akin to his "anorogenic" association.

Ternary AFM and CNK projections (Figure 4.4) demonstrate a superficial calc-alkaline trend for all units. Note the alkali-rich nature of even the silica-deficient rocks in the Numok Intrusive Suite. Alkali-lime indices (SiO_2 content at which Na_2O+K_2O = CaO) are difficult to calculate, as very few samples have CaO > ($Na_2O + K_2O$). Linear regression of all
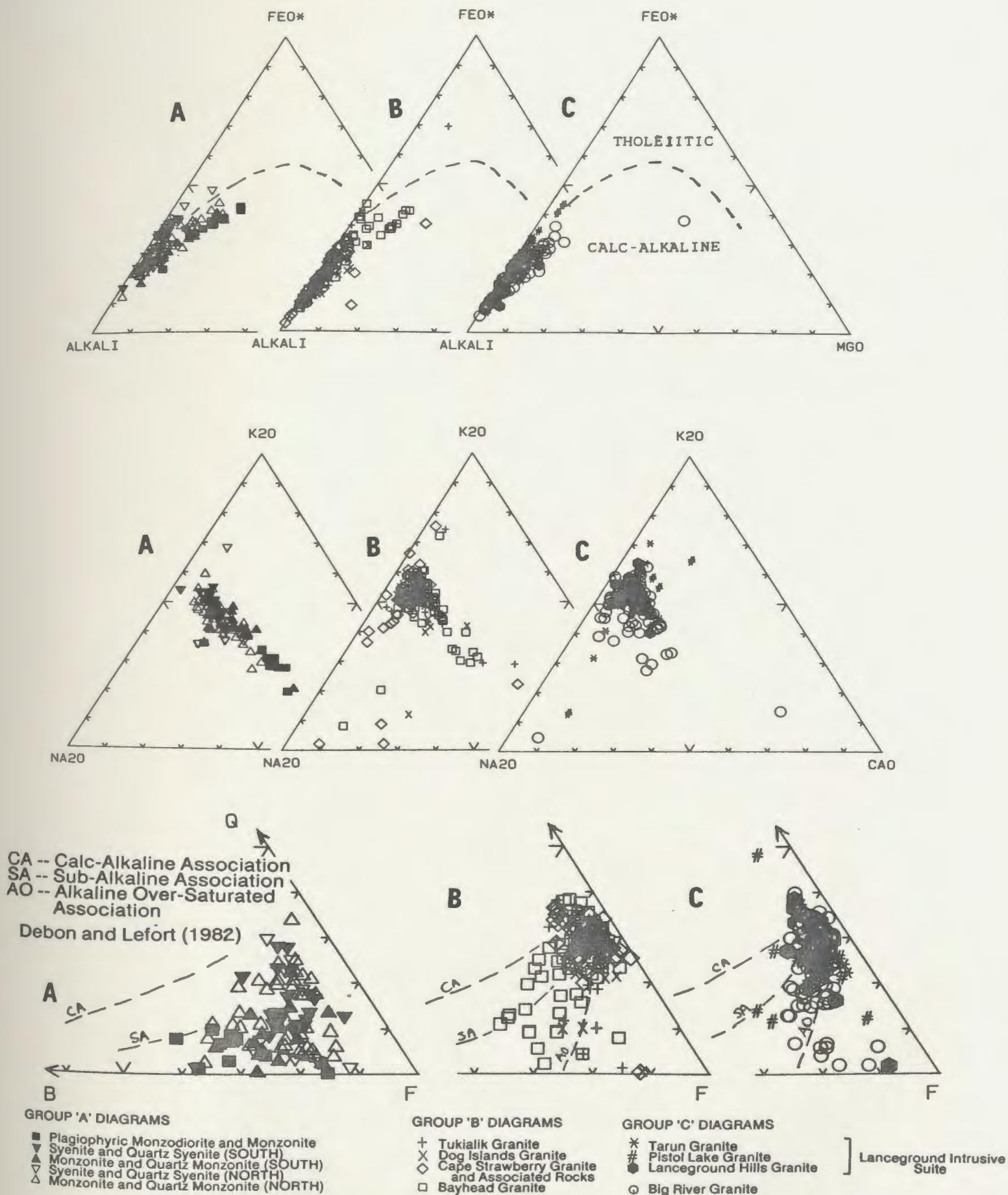
Figure 4.4. AFM, CNK and QBF projections for post-tectonic Makkovikian plutonic units. See text for discussion.

GROUP 'A' DIAGRAMS

- Plagiophyric Monzodiorite and Monzonite
- Syenite and Quartz Syenite (SOUTH)
- Monzonite and Quartz Monzonite (SOUTH)
- Syenite and Quartz Syenite (NORTH)
- Monzonite and Quartz Monzonite (NORTH)

GROUP 'B' DIAGRAMS

+ Tukialik Granite
X Dog Islands Granite
◇ Cape Strawberry Granite and Associated Rocks
□ Bayhead Granite

GROUP 'C' DIAGRAMS

* Tarun Granite
# Pistol Lake Granite
● Lanceground Hills Granite] Lanceground Intrusive Suite
⊙ Big River Granite

Figure 4.4 (continued). (Na_2O+K_2O) - SiO_2 projection for post-tectonic Makkovikian plutonic units. Alkaline and subalkaline fields from Irvine and Baragar (1971).

post-tectonic Makkovikian data suggests a value of ca. 55 % SiO_2, i.e. alkali-calcic in the terminology of Peacock (1931). The CNK diagram also illustrates minor alkali disturbance in the Strawberry Suite.

The Q-B-F ternary projection (Figure 4.4) of Debon and Lefort (1982) indicates an affinity to their "alkaline-oversaturated" association, rather than typical calc-alkaline suites. In the $(Na_2O+K_2O)-SiO_2$ plot (Figure 4.4), many of the Numok Intrusive Suite rocks fall in the alkaline field of Irvine and Baragar (1971).

Normative Compositions

No units contain significant normative corundum (Table 4.2). In the quartz - albite - anorthite - orthoclase quaternary system (Figure 4.5), only the Numok Suite contains significant anorthite. The total proportion of normative An in the quaternary system is ≤ 5% for virtually all of the siliceous granitoid units.

In the Q-Ab-Or projection, granites of the Strawberry and Lanceground Suites are clustered tightly around the
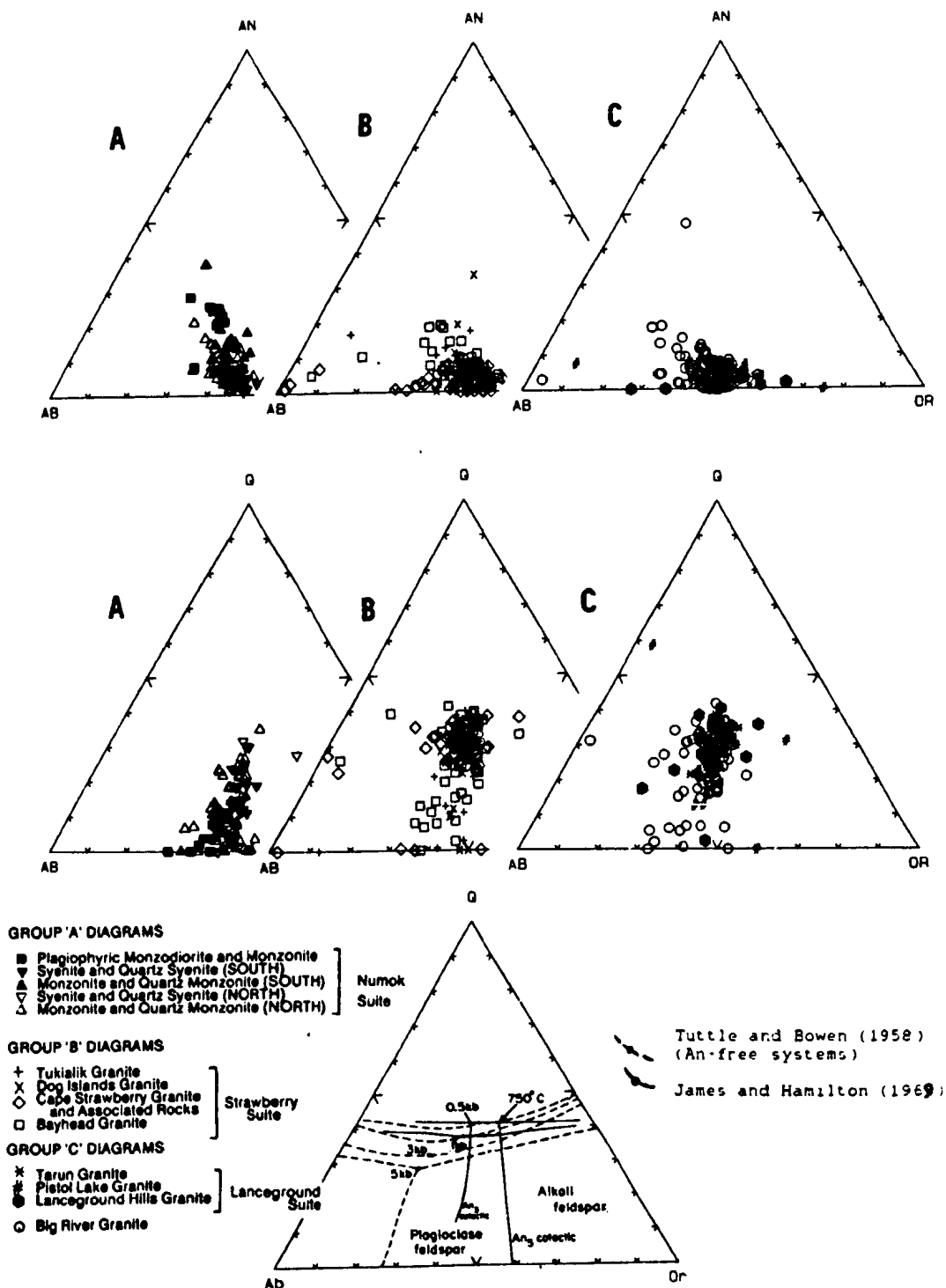
Figure 4.5. Variation of post-tectonic Makkovikian plutonic rocks in the quartz - albite - anorthite - orthoclase quaternary system. All norms are CIPW. See text for discussion.

ternary minimum for appropriate Ab/An ratios (James and
Hamilton, 1969). The Numok Suite defines a smooth trend
from quartz-free monzodiorites to granites that are close
to minimum melt compositions. This trend is coincident with
plagioclase - K-feldspar cotectic lines derived
experimentally by (James and Hamilton, 1969; Figure 4.5),
but these are not strictly applicable to the least evolved
rocks of the Numok Suite, which contain 7-20% An (relative
to quaternary system). The less differentiated members of
the Bayhead and Big River Granites cluster around this same
trend.

Trace Element Patterns

Octahedrally Co-ordinated Cation (OCC) Elements : V,
Cr, Cu, Ni, and Sc all show strong inverse correlation with
SiO_2 (e.g. V, Figure 4.6). These elements do not
discriminate between units.

Low Field Strength (LFS) Elements : Incompatible LFS
elements (e.g. Rb and Th, Figure 4.6) provide little
distinction between units. Rb defines two trends in the
Numok Intrusive Suite; many rocks with < 65% SiO_2 in the
southern zone show Rb contents similar to those of
siliceous granitoid units.

Rb and Th are enriched in Strawberry Suite granites,
and are scattered above ca. 70% SiO_2. Similar
disorganized variation is shown by U and Pb (not figured).

Sr and Ba show inverse trends against SiO_2 (Figure
4.6), and resemble patterns for compatible OCC trace
elements. Sr is highest in parts of the Numok Intrusive
Suite, particularily the southern area, where the
plagiophyric monzonite unit is probably partly a

Figure 4.6 . V, Rb, Th, Sr, Ba and F versus SiO_2 in post-tectonic Makkovikian plutonic units. See text for discussion.
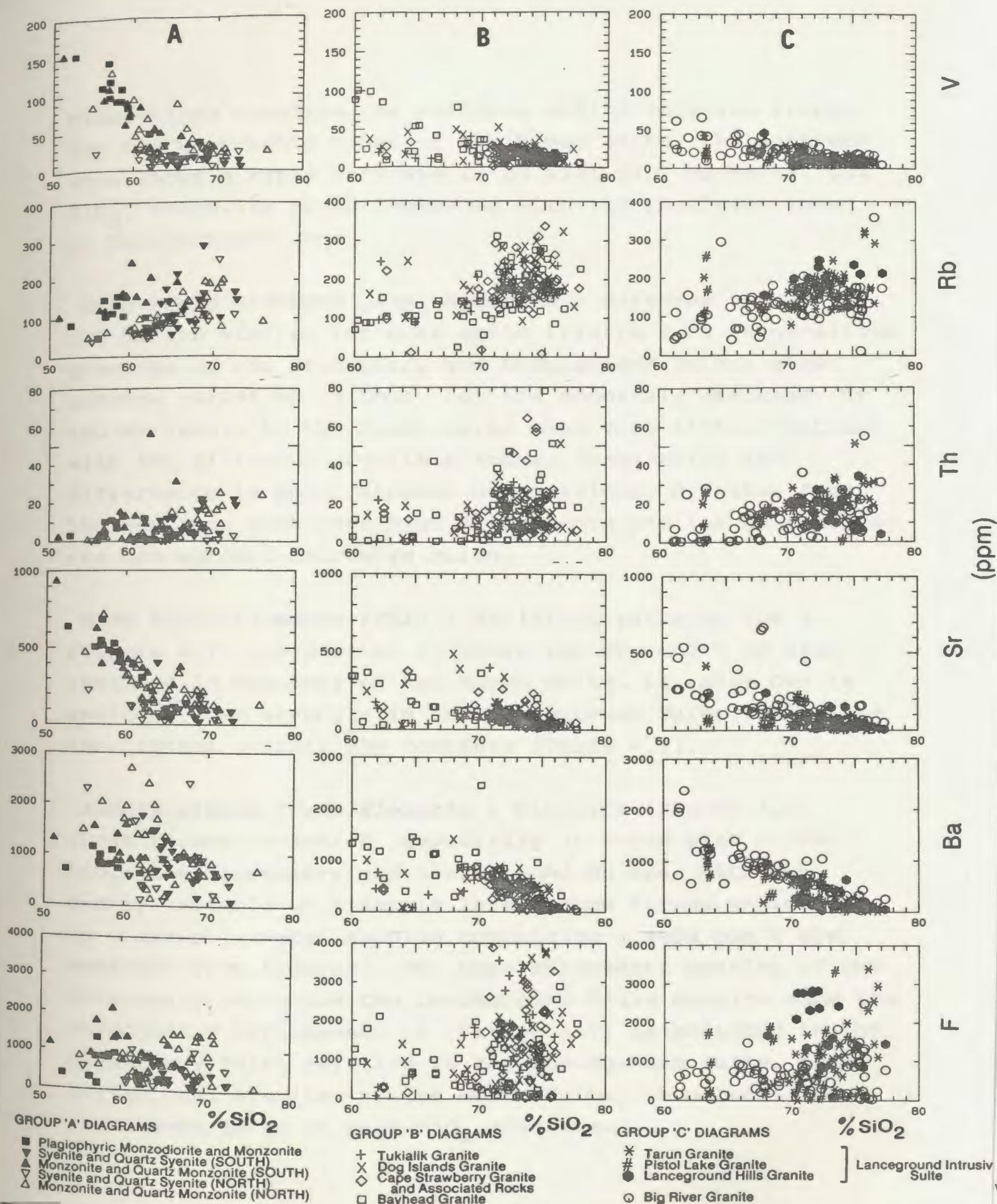
plagioclase cumulate. Ba patterns define separate trends
for the geographic zones of the Numok Suite. The northern
zone shows a rapid decrease in Ba with SiO_2 up to ca. 65%
SiO_2, where its trend coalesces with the shallower trend
of the southern zone.

High Field Strength (HFS) Elements : Patterns for Zr
and Nb are similar for most units (Figure 4.7). High-silica
granites of the Strawberry and Lanceground Suites show
extreme variation in both, but are generally enriched. Zr
and Nb levels in the Numok Suite show very little contrast
with the siliceous granitoid rocks, considering the
differences in major element compositions. Syenites from
the southern zone have high Zr contents similar to those of
the Lanceground Intrusive Suite.

Rare Earth Elements (REE) : Variation patterns for Y
(Figure 4.7) are similar to those for Zr, and Y is also
enriched in syenites of the Numok Suite. La (also Ce) is
enriched most strongly in the Lanceground Suite, which has
the highest overall REE contents (Table 4.2).

Indeterminate Trace Elements : Fluorine (Figure 4.6)
shows strong variation, especially in rocks with > 70%
SiO_2. The Strawberry and Lanceground Suites, although
highly variable at a sample level, show strong enrichment
as a group (several samples containing > 4000 ppm F are
excluded from figures). The Cape Strawberry granite of the
Strawberry Suite and the Lanceground Hills Granite show the
strongest F enrichment. Li (Figure 4.7) is enriched in the
Strawberry Suite relative to the Lanceground Suite. Both
suites, and syenites of the Numok Suite, show local
enrichment in Zn at high SiO_2 contents.
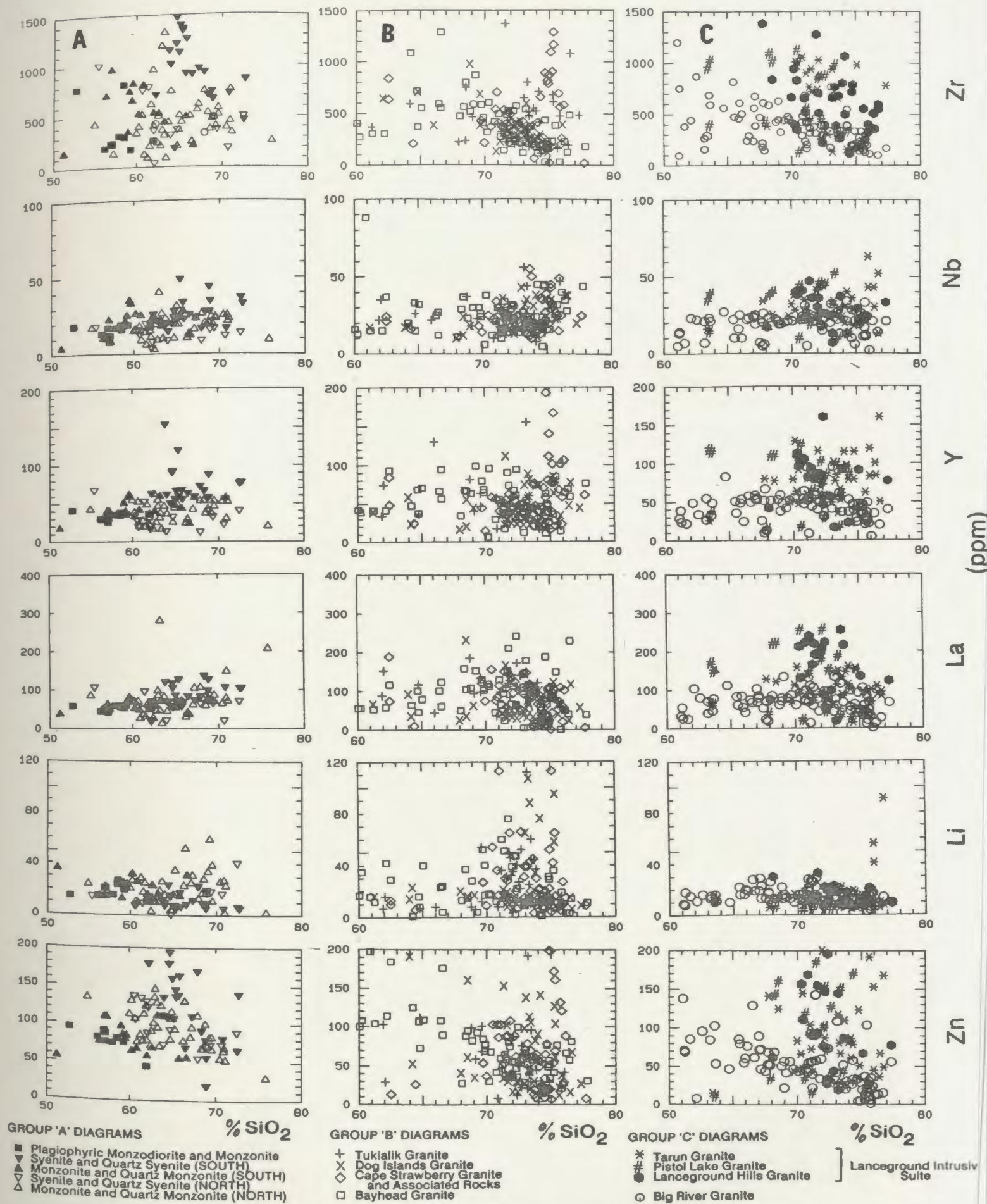
Figure 4.7 . Zr, Nb, Y, La, Li, Zn and F versus SiO$_2$ in post-tectonic Makkovikian plutonic units. See text for discussion.

Trace Element Ratios

K/Rb ratios (Figure 4.8) range from ca. 1000 in the northern area of the Numok Intrusive Suite to less than 150 in granites of the Strawberry Suite. The southern zone of the Numok Suite shows lower K/Rb than the northern zone.

Rb/Sr ratios range from 0.1 to 10.0 (Figure 4.8) and define flat-lying to slightly negative trends for all units.

Ba/Sr ratios (Figure 4.8) vary from 10.0 to 1.0, and define linear or curvilinear positive trends. The Numok Suite has two distinct trends; the southern zone trend is initially flat-lying (i.e. constant Ba, increasing Ba/Sr) whereas the northern zone has essentially constant Ba/Sr throughout. The Strawberry Intrusive Suite has a well-defined curved trend, where Ba/Sr initially increases to ca. 10.0, but decreases to < 1.0 in the most SiO_2-rich rocks. The Big River Granite shows a similar curved trend, but the Lanceground Intrusive Suite shows essentially constant Ba/Sr.

In comparison to reference trends for fractionation of common minerals (Figure 4.8, inset), these trends are consistent with fractionation of plagioclase and/or K-feldspar. The contrasting trends in the Numok Suite imply that plagioclase extraction was initially more important in the southern zone. The curved Ba/Sr trend of the Strawberry Intrusive Suite suggests an increase in the relative proportion of K-feldspar extracted (assuming that partition coefficients for both minerals remained constant). It is closely similar to the trend for the syn-tectonic Kennedy Mountain Intrusive Suite (Figure 3.10, p.89). The constant Ba/Sr trend of the Lanceground Intrusive Suite implies little or no plagioclase fractionation, consistent with its variably hypersolvus character.
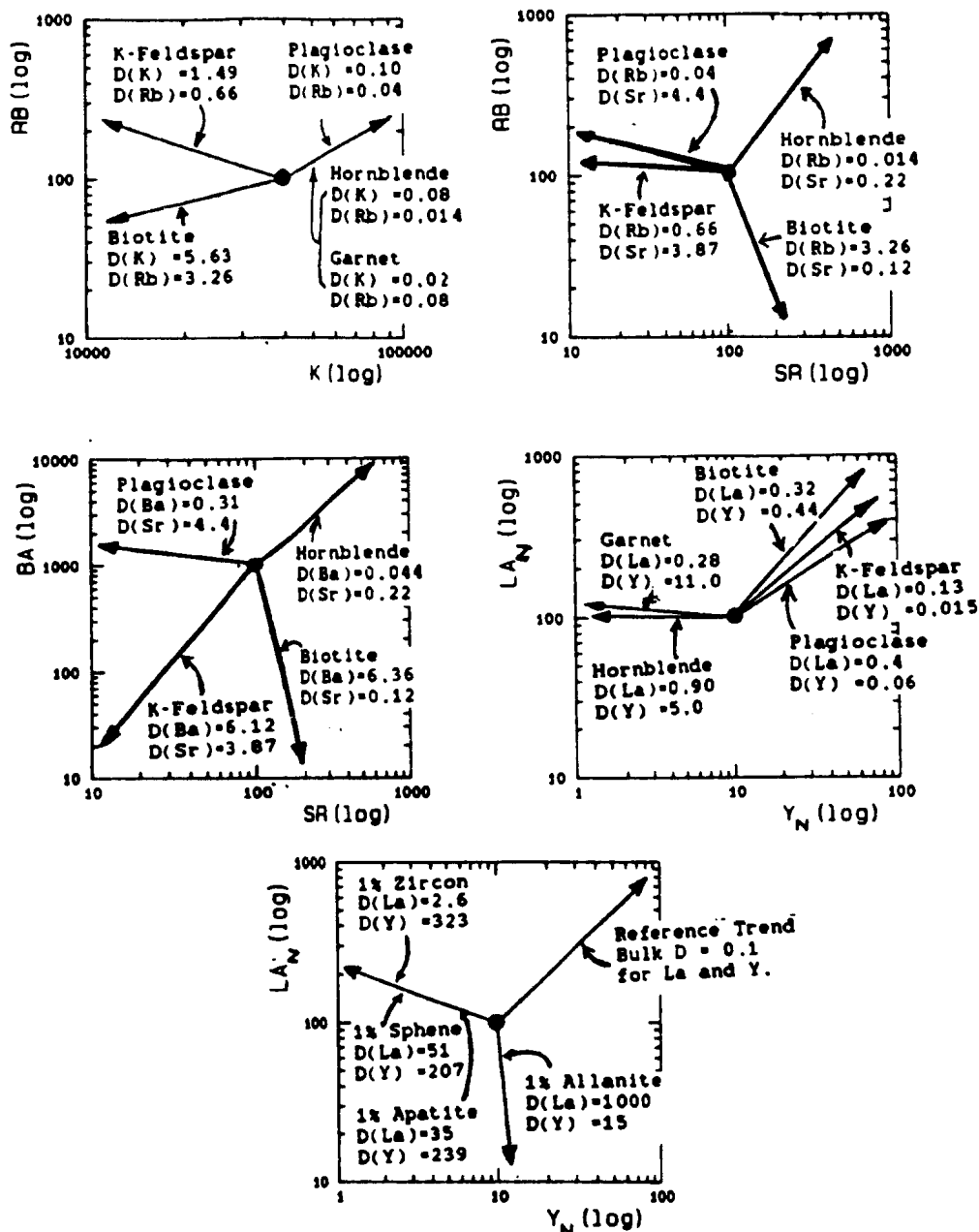
Idealized fractionation trends for Rayleigh fractionation (i.e. perfect separation of crystals and liquid). The La_N/Y_N trends for accessory phases show the effects of only 1% of each phase upon a reference trend where bulk partition coefficients for the remaining 99% of the fractionate are 0.1 for both La and Y. The latter approximates a "normal" path for fractionation of common silicates. Partition coefficent data from compilations by Arth (1976) and Hanson (1978) for most minerals, and from Gromet and Silver (1983) for allanite and sphene.
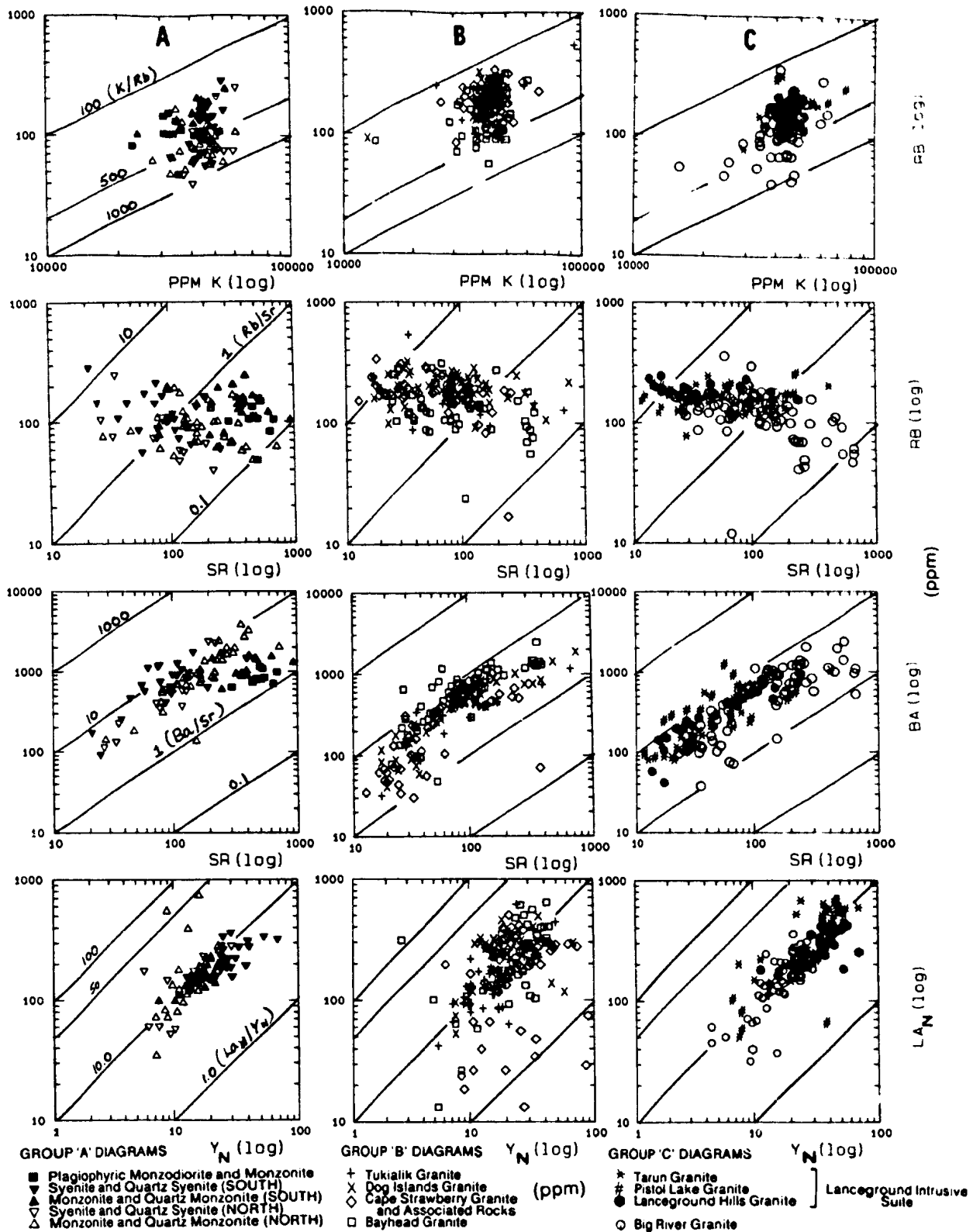
Figure 4.8 . Variation in the trace element ratios K/Rb, Rb/Sr, Ba/Sr and La_N/Y_N in post-tectonic Makkovikian plutonic rocks. See opposite for reference fractional crystallization trends.

La_N/Y_N ratios (both elements normalized to chondritic values) are remarkably consistent during evolution of the Numok Intrusive Suite and Lanceground Suite (La_N/Y_N ca. 10). Increases in both with SiO_2 (Figure 4.7) argue against significant extraction of accessory phases. The Strawberry Suite shows a similar range of values, but is locally anomalous ($La_N/Y_N < 10$, or even < 1). This is consistent with local fractionation of LREE-enriched phases such as allanite, which occurs in "cumulate" mafic mineral layers in some of these granites.

Rare Earth Element (REE) Patterns

REE patterns are similar for all post-tectonic Makkovikian units (Figure 4.9; data in Appendix B). The Numok Intrusive Suite shows the least fractionated REE pattern, but absolute REE abundances approach those shown by siliceous granitoid units. A monzonite from the northern zone shows a small negative Eu anomaly, but syenites from both zones appear to lack Eu anomalies. This is puzzling in view of evidence for feldspar fractionation outlined by Ba-Sr-Rb behaviour (Figure 4.8), but it is not yet clear if this absence is a general feature of syenites in the suite. K-feldspar was probably the dominant fractionating phase in these rocks, but should also generate a negative Eu anomaly (e.g. Hanson, 1978).

Strawberry Intrusive Suite granites show identical REE patterns that are characterized by steep LREE profiles, coupled with negative Eu anomalies and flat to slightly fractionated HREE patterns. These are closely similar to REE patterns from the syn-tectonic Kennedy Mountain Intrusive Suite (Figure 3.11, p.91). Patterns for the Lanceground Intrusive Suite are identical in shape to both,
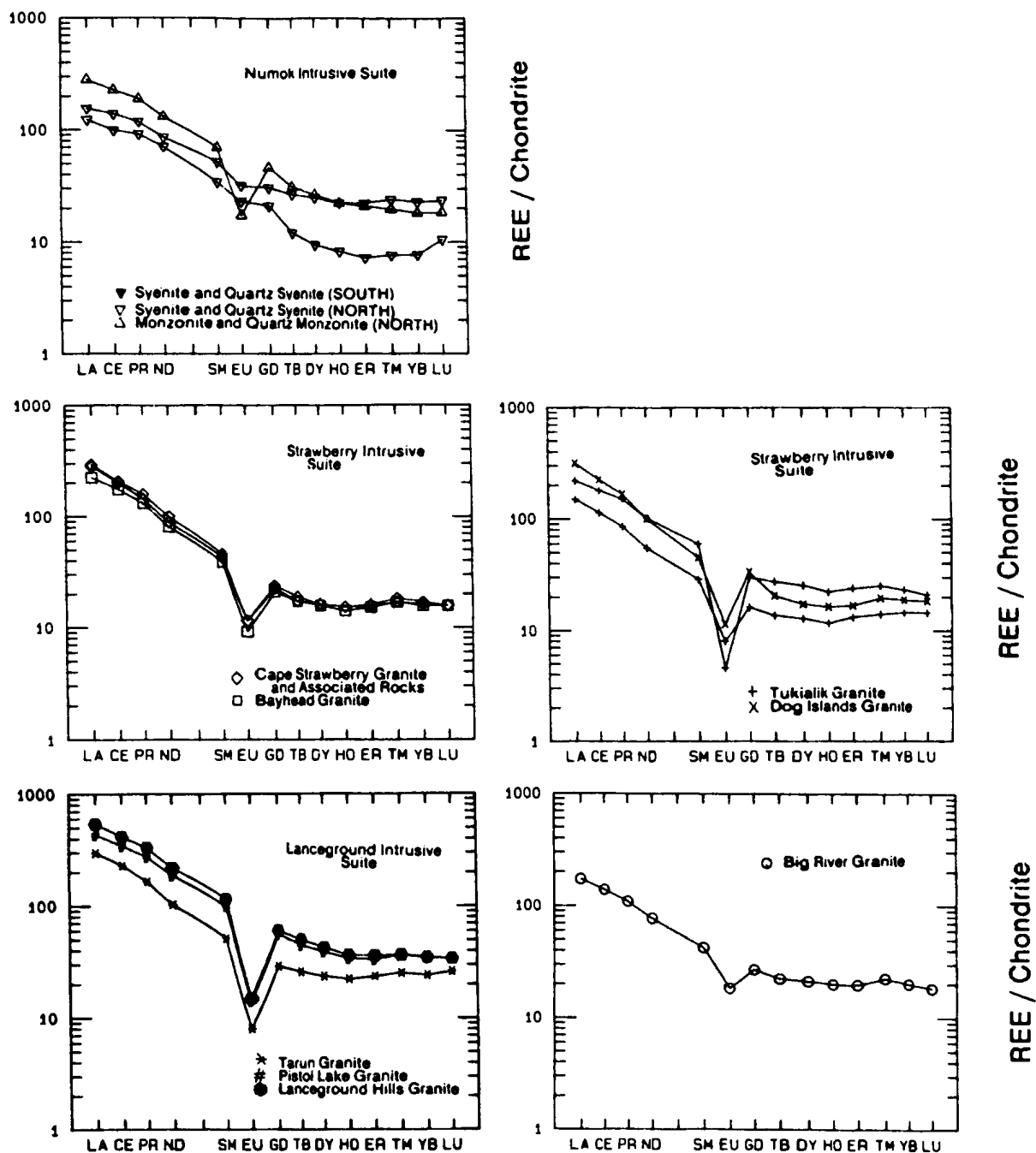
Figure 4.9 . Rare Earth element (REE) patterns for representative
post-tectonic Makkovikian plutonic rocks. Values are normalized to
chondritic values (listed in Appendix C).

but show higher overall REE abundances (up to 800 x
chondrite). The Big River Granite shows an unremarkable
pattern that resembles both of the above in general terms,
but has a smaller Eu anomaly.

4.3 SUMMARY AND DISCUSSION

Geological and Geochemical Continuity

All post-tectonic Makkovikian units described here are
of regional extent in the sense that they outcrop over
hundreds of square kilometres, or occur as discrete,
closely similar bodies dispersed over wide areas. Those
that retain contacts with country rocks show intrusive
relationships, and there is no sign of extensive
migmatization around them. They are generally homogeneous,
and contain xenoliths only in their marginal zones. They
are clearly discordant magma bodies that have risen from
depths well below the current level of exposure.

A generalized distinction can be made between the
Numok Intrusive Suite and siliceous granitoid rocks. The
former is dominated by quartz-poor rock types (monzonite to
quartz syenite) that are associated (in the south) with
plagiophyric monzodiorite and monzonite of probable
cumulate origin. Mafic inclusions in the agmatitic border
zone of the quartz monzonite unit (in the north) also
suggest a general association with mafic magmas.

Siliceous granitoid units, in contrast, are dominated
by quartz-rich, K-feldspar porphyritic, commonly
fluorite-bearing, biotite or biotite-hornblende granite and
alkali-feldspar granite. Although textural and
mineralogical differences allow suites and units to be
defined amongst these rocks, the similarities between them
far outweigh any differences.

The separation between the Numok Suite and these rocks is not, however, absolute; the most differentiated variants of the former include granites and alkali-feldspar granites, and some Numok Suite quartz syenites resemble the Lanceground Intrusive Suite. A possible link between them is suggested by local relict fayalite in both; this is an uncommon phase, reported mostly from granites of anorogenic or "rapakivi" associations (e.g. Anderson, 1983).

Siliceous granitoid rocks also have some features in common. For example all units locally contain minor blue sodic amphibole and/or relict aegirine-augite, and a small proportion of peralkaline rocks; such features are also common in anorogenic granitoid assemblages.

Trace element geochemistry further emphasizes the continuity of the post-tectonic assemblage. The Numok Intrusive Suite is distinct in terms of major element patterns (i.e. less siliceous, yet obviously alkali-rich), and also for some compatible OCC and LFS trace elements. However, it has REE, LFS and HFS element contents similar to siliceous granitoid units. The latter have very coherent trace element patterns. There are some absolute distinctions, e.g. higher F in the Strawberry Suite, and higher Zr, Y and REE in the Lanceground Suite, but there is an overwhelming similarity between all these rocks.

This geochemical continuity is also geographically continuous; the various units of the Strawberry Intrusive Suite show closely similar characteristics over large distances (125 km). Such continuity implies a close similarity in petrogenetic processes and source materials or magmas across this distance, and indicates that a single model is required for all these granites. It is particularly significant in interpretation of Nd isotopic

data from these rocks (Chapter 8). Similar arguments apply
to the Lanceground Suite, although the geographic area
represented by these rocks is somewhat smaller.

Origin of Compositional Variations

Numok Intrusive Suite : Trace element data (notably
Rb, Sr and Ba) indicate that compositional evolution
reflects feldspar ($\pm$ mafic mineral) fractionation, and that
there were differences in the fractionation histories of
northern and southern zones. In the southern zone,
extraction of plagioclase was initially prevalent; the
subsequent Ba depletion indicates increasing removal of
K-feldspar. In the northern zone, K-feldspar fractionated
throughout evolution, and both feldspars were removed in
relatively constant proportions. This is consistent with
the presence of the plagiophyric monzonite (which is
probably a plagioclase cumulate) in the southern zone. The
differences between northern and southern zones suggest
that each represents a different level or magma batch
within the Numok magma chamber. The identity and
composition of the parental magma is uncertain, as the
least evolved rocks (plagiophyric monzonites) are not
liquid compositions. To produce the observed compositional
range, it must have been at least as mafic as monzonite,
assuming that the plagiophyric unit is a crystal
accumulation.

Strawberry Intrusive Suite : Rb, Sr and Ba data
indicate that evolution of these magmas was dominated
initially by plagioclase fractionation but that K-feldspar
quickly became dominant. This is consistent with the
presence of plagioclase phenocrysts in the least
differentiated rocks (e.g. Bayhead Granite).

Euhedral accessory minerals in mafic mineral layers in
some of these granites imply that fractionation of such
phases became important at high SiO_2 contents but, as
most granites are enriched in HFS elements and REE, this
must have been a late phenomenon. Fine-grained granites of
the Poodle Pond area, which are interpreted as high-level
sills linked to subsurface Cape Strawberry Granite, show
depletion of LREE and Fluorine relative to normal levels in
the suite (Table 4.2). Such features are compatible with
extraction of biotite and allanite (± amphibole) in the
latter stages of evolution. The presence of cumulus
textures implies a low viscosity during crystallization.
Tuffisite breccias and miarolitic cavities indicate that
the Cape Strawberry Granite attained high emplacement
levels and exsolved volatiles, which also implies a low
solidus temperature.

The high F content of the suite (as there is evidence
of volatile loss, this is probably an underestimate of the
actual F content at the time of emplacement) provides an
explanation for these features, as fluorine reduces
viscosity and solidus temperatures in experimental melts
(e.g. Dingwell, 1988).

Kerr (1988) has shown that the Cape Strawberry Granite
shows well-developed compositional variation, independent
of obvious petrographic contrasts, that is related to
distance from its southern contact. SiO_2, U, Rb, Th and
Pb increase towards this contact, and Ba, Sr and Li are
depleted. HFS and RE elements show contradictory behaviour;
they are depleted towards some areas of the contact, but
enriched in others. Zonation patterns of this type resemble
those reported from rhyolitic ash-flow tuffs (e.g Hildreth,
1979, 1981) and also from high-silica granites (e.g., Tuach
et al., 1986). Although fractional crystallization,

particularly involving accessory phases, can account for
such patterns (e.g. Michael, 1983), in-situ geochemical
gradients of this type may also reflect liquid-state
processes such as thermogravitational diffusion or
convective fractionation (e.g., Hildreth, 1981; Rice, 1981;
MacDonald and Smith, 1988). Dingwell (1988) pointed out that
F-enrichment may promote the operation of such processes,
by a direct increase in diffusion rates, and also by
increasing the longevity of magmatic systems via solidus
depression. Processes of this nature may have modified and
disturbed trace element patterns produced by fractionation.
Strong variation in a range of trace elements above ca. 70%
SiO_2 (Figures 4.6; 4.8) is probably a result of these
effects.

Lanceground Intrusive Suite : The Lanceground
Intrusive Suite is locally a hypersolvus granite. Such
characteristics imply relatively dry magma and high levels
of emplacement. Geochemical variation is largely a result
of K-feldspar fractionation, as the Ba/Sr trend is very
close to the ideal Rayleigh fractionation trend for this
mineral (Figure 4.8). Mineralogical similarities (e.g.
fayalitic olivine, local hypersolvus character) suggest a
genetic link between the Lanceground Suite and syenitic
rocks of the Numok Suite. HFS element and REE enrichment,
and Sr depletion, is qualitatively consistent with
derivation by fractionation of the Numok Suite, which shows
similar tendencies at a lower SiO_2 content.

Big River Granite : Evolution of the Big River Granite
appears to have been generally similar to that of the
Strawberry Intrusive Suite, i.e. initial plagioclase-
dominated fractionation, followed by increasing removal of
K-feldspar.

Pseudorapakivi textures are consistent with this interpretation, but provide an interesting problem in themselves. Classical rapakivi textures are commonly interpreted to result either from intersection of the liquidus and feldspar solvus due to high vapor pressure (Tuttle and Bowen, 1958), or from expansion of the plagioclase field in the granite system due to vapor pressure reduction (Stewart, 1959). Both readily explain mantling of K-feldspar by plagioclase, but do not provide a simple explanation for reverse textures, which apparently require <u>contraction</u> of the plagioclase stability field. The best explanation is that crystallization of the Big River Granite took place close to the plagioclase-alkali feldspar cotectic, where a small change in physical conditions would produce the required effect. This is supported by the proximity of the Big River data to the cotectic lines determined by James and Hamilton (1969) (Figure 4.5).

Similarity of Post-Tectonic and Syn-Tectonic Makkovikian Associations

There are many similarities between post-tectonic Makkovikian plutonic rocks and some of the syn-tectonic associations described in Chapter 3. This is most obvious in the case of the syn-tectonic metaluminous-peralkaline association comprising the Long Island quartz monzonite and Kennedy Mountain Intrusive Suite. In contrast, there are no presently recognized post-tectonic equivalents of the syn-tectonic peraluminous association.

Table 4.3 lists average major element, trace element and partial CIPW normative compositions for several syn- and post-tectonic suites. There is a good correspondence between the granites of the Strawberry and Kennedy Mountain

Table 4.3 . Comparison of average compositions for selected syn-tectonic and post-tectonic Makkovikian plutonic units.

UNIT	10		20		21		11 (all)		11 (unaltd)	
n1	15		57		40		108		97	
n2	5		12		6		22		23	
(wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	63.32	1.27	62.31	4.27	65.52	3.92	73.74	3.09	73.58	2.98
TiO2	0.88	0.06	0.78	0.29	0.63	0.29	0.28	0.18	0.29	0.19
Al2O3	15.81	0.24	16.69	1.49	15.07	1.21	12.65	1.13	12.67	1.15
Fe2O3	1.79	0.37	1.72	0.75	1.44	0.61	1.29	0.67	1.24	0.70
FeO	3.06	0.73	3.41	1.12	3.66	1.75	1.34	1.13	1.39	1.17
MnO	0.10	0.01	0.12	0.05	0.15	0.07	0.06	0.03	0.06	0.02
MgO	1.25	0.42	1.22	0.87	0.40	0.29	0.19	0.24	0.19	0.25
CaO	2.95	0.48	2.92	1.30	1.76	0.71	0.84	0.61	0.82	0.56
Na2O	4.27	0.25	4.57	0.41	4.51	0.57	4.40	1.08	4.00	0.48
K2O	4.75	0.49	5.14	1.09	5.81	0.67	4.29	1.56	4.85	0.64
P2O5	0.26	0.03	0.24	0.14	0.15	0.13	0.05	0.05	0.05	0.05
LOI	0.63	0.23	0.58	0.35	0.46	0.23	0.45	0.21	0.45	0.22
TOTAL	99.07		99.67	0.00	99.54		99.58		99.57	

(ppm)	Trace Elements									
Li	22.7	5.7	21.0	9.7	13.0	7.6	14.6	11.3	14.9	11.7
F	860.5	212.7	928.9	436.3	427.8	270.3	1014.0	847.4	1029.9	803.8
Sc	9.6	1.7	10.5	2.1	11.0	3.8	1.3	0.9	1.4	0.9
V	74.6	19.6	55.9	37.5	17.7	10.0	15.6	12.7	15.9	13.4
Cr	5.5	3.5	7.0	9.9	3.4	2.4	5.0	3.8	4.7	3.8
Ni	2.6	1.9	3.7	4.7	1.1	0.5	1.4	1.2	1.3	1.2
Cu	9.1	3.8	13.6	9.5	6.4	3.1	3.8	3.8	3.9	3.9
Zn	74.1	8.5	86.3	23.4	114.3	44.2	81.8	53.3	77.1	29.9
Ga	18.3	1.2	20.5	2.9	21.6	6.3	16.6	7.3	16.5	6.8
Rb	126.4	24.2	121.9	47.9	110.8	54.5	134.6	64.9	153.5	47.1
Sr	327.6	39.0	329.4	166.6	108.5	77.0	62.0	75.6	60.8	77.5
Y	36.5	1.9	39.2	13.6	53.5	19.9	72.2	30.5	70.9	28.9
Zr	236.6	83.2	486.3	255.9	794.8	411.2	388.7	146.8	387.0	151.8
Nb	14.2	1.1	19.1	8.5	21.3	6.9	28.3	13.8	27.9	14.0
Mo	4.3	0.5	4.1	1.0	3.4	1.1	3.6	1.8	3.7	1.9
Sn	1.0	0.0	2.7	2.7	1.3	0.5	3.3	2.1	3.5	2.5
Cs	1.3	1.2	1.6	1.7	0.7	0.4	0.7	0.4	0.6	0.4
Ba	1424.0	116.2	1099.0	558.0	787.7	542.1	433.8	433.5	453.1	411.7
La	53.3	4.9	64.8	31.7	77.2	26.4	78.9	35.2	76.6	33.3
Ce	102.7	6.1	131.0	63.2	156.4	54.7	163.1	66.9	158.7	65.7
Sm	9.2	0.8	13.3	3.1	14.5	3.8	12.4	3.7	12.6	3.5
Yb	2.5	0.0	3.8	2.1	5.3	0.0	7.2	3.6	7.7	3.2
Hf	8.0	1.2	11.9	3.5	14.3	5.0	12.2	3.4	12.1	3.1
Pb	15.9	3.9	15.9	6.6	15.8	7.1	19.3	10.6	20.3	10.4
Th	9.2	3.0	9.1	10.7	5.1	4.8	15.7	9.7	15.2	9.6
U	4.8	0.9	3.1	1.7	2.4	1.4	4.8	2.9	4.7	3.0

(wt%)	CIPW norm (partial)									
Q	12.25	1.76	8.02	6.40	10.77	7.74	29.87	6.15	29.80	6.01
C	0.00	0.00	0.05	0.18	0.02	0.05	0.01	0.06	0.02	0.06
Or	28.50	2.93	31.47	4.81	32.52	5.39	25.57	9.35	28.89	3.89
Ab	36.71	2.01	38.96	3.48	40.28	5.85	37.39	8.96	34.11	4.02
An	10.08	1.50	9.37	4.48	5.28	3.78	2.16	2.24	2.30	2.27
Di	2.88	1.35	2.85	1.48	3.52	2.25	1.15	1.07	1.08	0.87
Hy	4.65	1.72	4.53	2.26	3.22	2.08	1.08	1.93	1.22	2.00
Ol	0.00	0.00	0.41	1.09	0.61	1.36	0.00	0.00	0.00	0.00
Mt	2.64	0.55	2.41	0.96	2.06	0.78	1.63	0.78	1.58	0.75
Il	1.69	0.12	1.48	0.56	1.21	0.49	0.54	0.34	0.54	0.36

KEY TO UNITS (NIS - Numok Intrusive Suite, KMIS - Kennedy Mountain Suite)
10 -- Long Island Quartz Monzonite (all data)
20 -- Numok Intrusive Suite (Monzonite to Quartz Monzonite)
21 -- Numok Intrusive Suite (Syenite to Quartz Syenite)
11 (all data) - (KMIS) All data including albitized rocks
11 (unaltd) - (KMIS) Excluding rocks with N/N+K < 0.3 or > 0.65
n1 -- Number of analyses for all elements except those listed below
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf

Table 4.3 (continued).

UNIT	23-26		24		27-29		30	
n1	197		55		82		79	
n2	142		47		66		13	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	71.29	4.71	72.81	3.56	72.12	2.93	70.11	5.15
TiO2	0.31	0.27	0.21	0.11	0.32	0.19	0.39	0.22
Al2O3	13.68	1.55	13.20	1.50	13.22	1.34	14.43	1.74
Fe2O3	1.05	0.74	1.14	0.80	1.21	0.57	1.16	0.55
FeO	1.68	1.47	1.23	0.81	1.44	0.87	1.49	0.97
MnO	0.06	0.06	0.05	0.05	0.06	0.04	0.06	0.04
MgO	0.36	0.50	0.27	0.55	0.18	0.17	0.50	0.84
CaO	1.14	1.04	0.91	1.17	0.88	0.47	1.36	1.20
Na2O	4.09	0.86	4.21	1.26	3.97	0.61	4.28	0.75
K2O	5.12	1.10	4.97	1.33	5.47	0.90	5.11	1.01
P2O5	0.07	0.09	0.04	0.03	0.04	0.04	0.10	0.08
LOI	0.67	0.37	0.67	0.60	0.53	0.20	0.58	0.29
TOTAL	99.52		99.71		99.44		99.57	
(ppm)								
Li	25.0	23.5	26.5	23.8	13.9	11.7	14.8	6.2
F	1420.0	1141	1541.1	1021	1244.6	935.7	688.5	462.5
Sc	3.1	4.1	1.9	1.7	3.8	5.3	2.4	0.9
V	23.3	29.2	20.4	41.9	12.8	7.7	21.5	17.1
Cr	5.1	6.5	6.3	7.9	3.7	2.9	4.8	13.7
Ni	2.2	3.9	2.6	5.8	1.5	1.8	2.6	7.9
Cu	9.3	38.4	11.3	44.8	6.0	9.2	6.3	6.1
Zn	75.1	69.6	84.3	82.3	89.6	59.6	54.8	42.8
Ga	16.9	8.6	17.6	10.2	21.4	10.0	15.2	5.2
Rb	178.4	65.0	176.1	62.1	172.5	44.1	127.8	51.8
Sr	111.7	130.2	77.5	71.8	61.2	65.8	160.7	151.6
Y	55.4	43.8	64.3	46.9	74.4	32.8	42.5	17.2
Zr	491.5	558.5	471.5	418.2	675.7	439.3	368.8	210.3
Nb	26.0	21.0	29.9	33.4	29.3	11.1	19.1	7.2
Mo	4.3	7.7	3.7	2.0	4.3	2.3	3.7	1.2
Sn	5.8	9.9	5.0	3.2	4.0	2.6	2.7	2.7
Cs	1.2	1.0	1.1	0.7	1.1	0.7	0.7	0.6
Ba	501.9	382.6	344.9	264.0	329.6	260.1	660.8	482.6
La	90.7	111.7	75.4	46.8	122.8	62.6	63.1	30.2
Ce	178.7	197.0	156.9	84.8	247.2	121.1	126.8	59.2
Sm	13.1	10.4	12.8	6.4	20.8	9.8	10.4	3.9
Yb	6.6	4.7	7.6	5.1	8.8	4.3	4.2	2.0
Hf	13.3	13.3	13.3	7.5	19.1	10.3	10.1	3.0
Pb	37.3	205.3	23.3	9.6	24.5	13.5	17.6	11.2
Th	18.3	20.5	23.4	28.3	18.9	8.0	13.0	9.6
U	5.8	7.0	8.0	11.9	5.5	2.3	4.5	2.6
(wt%)								
Q	24.90	9.23	27.17	8.65	26.22	7.51	22.16	9.88
C	0.12	0.23	0.07	0.14	0.10	0.70	0.06	0.14
Or	30.38	5.96	29.63	7.92	32.64	5.34	30.45	6.00
Ab	34.90	7.35	35.58	10.85	33.79	5.15	36.54	6.34
An	3.66	2.94	2.43	1.67	1.90	1.64	4.97	4.19
Di	1.28	2.82	1.25	4.29	1.62	1.35	1.11	1.66
Hy	2.15	2.26	1.39	1.32	0.96	1.05	1.81	1.34
Ol	0.03	0.26	0.00	0.02	0.00	0.00	0.18	1.60
Mt	1.38	1.00	1.25	0.98	1.63	0.77	1.60	0.82
Il	0.61	0.52	0.39	0.22	0.62	0.36	0.74	0.43

KEY TO UNITS (SIS - Strawberry Suite, LIS - Lanceground Suite)
23-26 -- Strawberry Intrusive Suite (all data)
24 -- Cape Strawberry Granite and Related Rocks
27-29 -- Lanceground Intrusive Suite (all data)
30 -- Big River Granite (all data)

n1 -- Number of analyses for all elements except those listed below
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf

Intrusive Suites, especially when altered granites with
N/N+K < 0.3 or > 0.65 are excluded from the latter. This
complements their obvious similarity in texture and
mineralogy, if the effects of deformation are disregarded.
However, alkali disturbance is not present to the same
extent in the Strawberry Suite, although there are signs of
some minor effects (e.g. Figure 4.4). The Long Island
Quartz Monzonite and Numok Intrusive have similar major
element compositions, but dissimilar trace element patterns
(Table 4.3).

Geochronological Relationships

The geochemical continuity discussed above is
consistent with closely similar U-Pb and Rb-Sr ages
obtained from the Island Harbour Bay Intrusive Suite, Long
Island Quartz Monzonite, the Numok Intrusive Suite and the
Big River Granite, all of which fall in the interval 1800 ±
15 Ma (Loveridge et al., 1987; Gandhi et al., 1988; Krogh
et al., in prep). Data from the Strawberry Intrusive Suite
are more difficult to assess; these rocks may be somewhat
younger at ca. 1760 Ma. These geochronological and
geochemical data indicate that "syn-tectonic" and
"post-tectonic" Makkovikian associations are (at least in
part) manifestations of the same event. They are regarded
by the author as closely related, and, in subsequent
chapters (e.g. Chapter 9), are treated as a single
assemblage.

They may collectively represent a single pulse of
magmatism that transcended a very short-lived deformational
event -- i.e., the age difference between "syn-tectonic"
and "post-tectonic" suites is real, but below isotopic
resolution. A second possibility is that late Makkovikian

deformation at ca. 1800 Ma may have been heterogeneous in nature. As discussed recently by Paterson and Tobisch (1988), the response of plutons to deformation is highly variable, and the use of foliations to date them may be misleading. As neither deformation or intrusion are instantaneous events, the distinction between these two alternatives is largely semantic.

CHAPTER FIVE
LABRADORIAN PLUTONIC ROCKS

Chapter Abstract

Labradorian plutonic rocks are undeformed suites for which geochronology and/or field relationships indicate ages between 1670 and 1600 Ma. There is no evidence of Labradorian deformation that preceded or accompanied their emplacement in the study area, but deformation and metamorphism of this age is widespread in high-grade terranes to the south. Labradorian units in the southwest of the area have variably-developed east-trending foliations, that are presumed to record Grenvillian deformation. The Labradorian assemblage is characterized by two contrasting groups of rocks that were derived respectively from mafic parental magmas and more siliceous granitoid magmas.

The Adlavik Intrusive Suite (ca. 1650 Ma) is a mafic to intermediate association that forms a complex, multiphase, layered intrusion and a number of isolated bodies. These mafic rocks are compositionally and texturally diverse, and include ultramafic rocks (originally pyroxenites), layered mafic cumulate rocks, plagioclase-cumulate leucogabbro, diabase and pegmatitic gabbro. These are associated with lesser amounts of diorite and monzodiorite. Field relationships are exceedingly complex, and suggest multiple batches of mafic magma, including both gabbroic and gabbronoritic compositions. Cumulate textures are widespread. An original pyroxene (± olivine) -bearing mineralogy was variably transformed to an amphibole-bearing assemblage, probably via late-magmatic or deuteric volatile build-up during crystallization. The gabbro is moderately K_2O-rich, and shows major and trace element affinity to "shoshonitic" basalts, and possibly to "appinitic" gabbro suites associated with some Phanerozoic granites.

The Mount Benedict Intrusive Suite (ca. 1650 Ma) ranges in composition from gabbro and diorite to alkali-feldspar granite, but is dominated by hornblende-biotite monzonite, syenite and quartz syenite. The suite is crudely layered, with evolved compositions at high elevations. The least evolved rocks are locally olivine-bearing plagioclase cumulates that resemble the Adlavik Suite. Variably preserved plagioclase phenocrysts in all members of the suite imply significant fractionation of this mineral. Well-defined geochemical trends within the suite are

consistent with derivation from a mafic to intermediate parent
by sequential fractionation of mafic minerals, plagioclase and
K-feldspar. Strong incompatible element enrichment is consistent
with this extended fractionation history, and trace element
modelling confirms that Adlavik Suite mafic magmas
are a possible parent composition. The Adlavik and Mount
Benedict Suites are thus regarded as closely related,
complementary associations.

The Monkey Hill Intrusive Suite (ca. 1640 Ma) comprises
several small, closely similar, epizonal, biotite-leucogranite
plutons that probably represent cupolas connected to a larger
body at depth. These are slightly peraluminous, and depleted in
fluorine, HFS elements and REE. Two plutons that belong to the
suite are associated with endocontact Mo and exocontact Mo-Cu (
± Pb-Zn) mineralization, and show strong depletion in a range of
trace elements. The latter is probably due to hydrothermal
activity associated with mineralization. Two ca. 1630 Ma old
granitoid plutons in the southwest of the area (Witchdoctor and
Burnt Lake Granites) have closely similar petrographic and
geochemical features, contain minor muscovite and garnet, and
are also associated with Mo mineralization. These show evidence
of Grenvillian deformation, as they lie close to the Benedict
Fault zone.

The Otter Lake - Walker Lake Granitoid (ca. 1650 Ma) is a
regionally extensive, variably deformed, porphyritic granitoid
suite ranging from biotite-hornblende quartz monzonite to
biotite granite. It has a mildly peraluminous composition, and
is generally poor in fluorine, HFS elements and REE.

As a group, Labradorian siliceous granitoid units differ
from their Makkovikian counterparts in their lack of
transitional peralkaline behaviour, general peraluminous
affinity and lack of fluorine, HFS element and REE enrichment.
Such features probably reflect different source materials and/or
generative processes for the two groups of granitoid rocks,
rather than different fractionation histories or hydrothermal
effects in epizonal plutons.

Introduction

This association comprises post-Makkovikian, largely undeformed, post-tectonic plutonic rocks for which geochronological data and/or field relationships suggest ages between 1670 and 1600 Ma. As discussed previously (Chapter 4), "post-tectonic" does not imply a universal absence of deformation, as some units in the south have east-trending foliations of probable Grenvillian age. There is no evidence of Labradorian deformation in the study area. The term "anorogenic", however, is not appropriate for these plutons, as there is clear evidence for Labradorian deformation and metamorphism in high-grade terranes to the south (e.g. Wardle et al., 1986). Labradorian plutonism may thus be temporally related to orogenesis, but the study area apparently lay outside the zone affected directly by metamorphism and deformation.

Labradorian plutonic rocks are divided into five main associations. The Adlavik Intrusive Suite consists of layered gabbro, leucogabbro and diorite. The Mount Benedict Intrusive Suite includes minor diorite and gabbro of similar aspect, but is dominated by monzonite to quartz syenite. The Monkey Hill Intrusive Suite comprises a number of small, leucocratic, epizonal granite plutons. The Witchdoctor and Burnt Lake Granites are similar leucocratic granites. The Otter Lake - Walker Lake Granitoid is a regionally extensive porphyritic quartz monzonite to granite unit. The latter two associations have been affected by Grenvillian deformation.
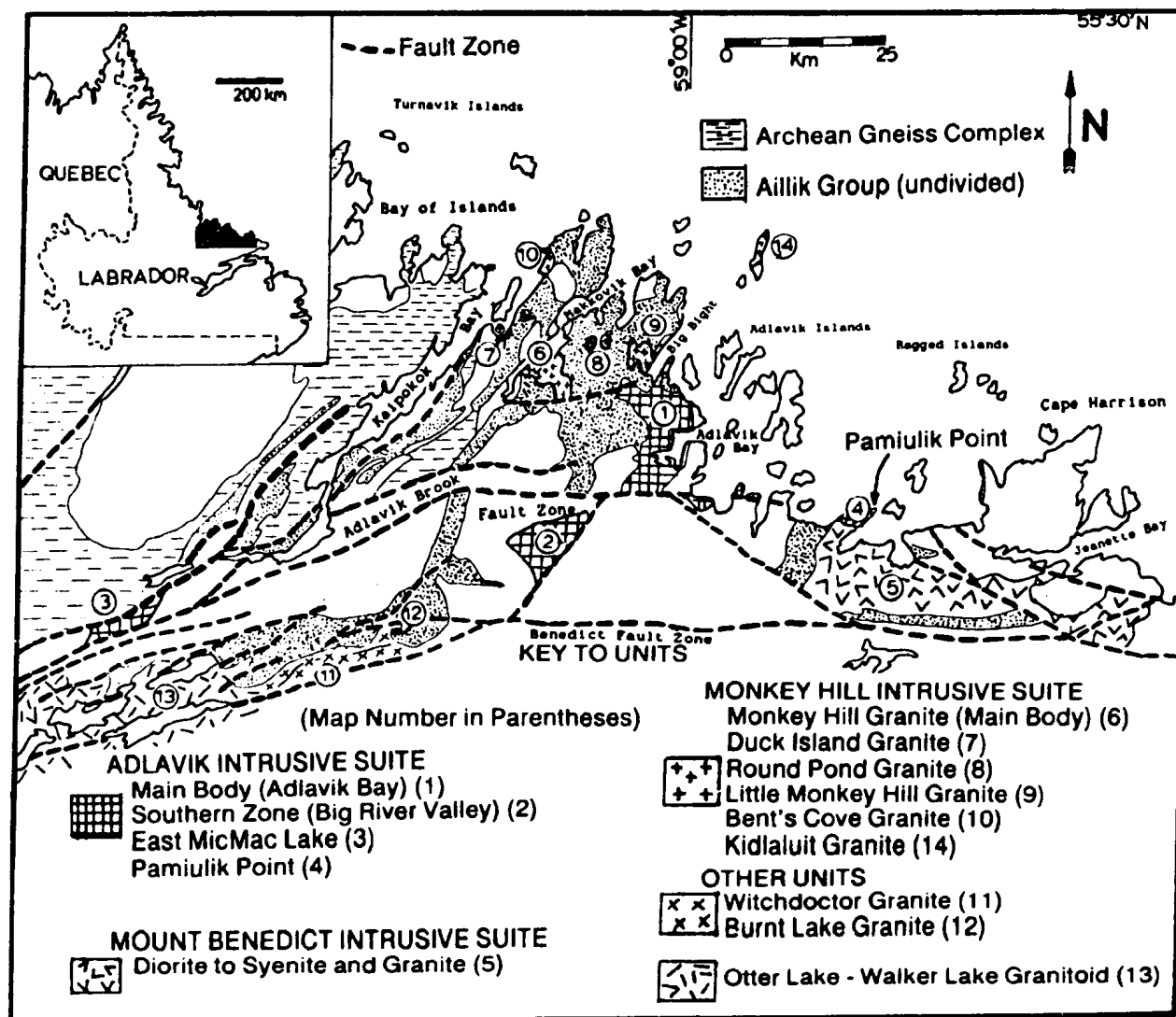
Figure 5.1. Summary map illustrating the distribution and extent of Labradorian plutonic units.

Table 5.1. Key features of Labradorian plutonic units.

Map Unit	Suite/Unit/Age	General Characteristics	Textural Characteristics
40.1 40.2 40.3 40.4	ADLAVIK INTRUSIVE SUITE Gabbro, Gabbronorite and Leucogabbro	Texturally variable, layered assem- blage of ultramafic rocks, gabbro, gabbronorite, plagioclase cumulate leucogabbro, and diorite. All of the above are cut by aqmatitic composite diabase (commonly net- veined) and by coarse pegmatitic gabbro.	Dominantly coarse-grained to very coarse-grained. Cumulate layering is variably developed. Mafic cumulates occur at the base and/or margin of the intrusion, and also occur sporadically within the dominant plagioclase cumulate facies.
41.1 41.2 41.3 41.4	Diorite and Monzodiorite 1649 +/- 1 Ma [U-Pb zircon] (Krogh et al., in prep.)	Homogeneous, grey to yellow-brown, massive, locally plagioclase- porphyritic Px-Hb or Hb-diorite, monzodiorite to (locally) monzonite and syenite.	Generally coarse-grained and homo- geneous. Locally displays wispy mafic mineral layering, and thin mafic cumulate zones. Contains xenoliths of gabbro, leucogabbro and mafic cumulate.
42.0	MOUNT BENEDICT INTRUSIVE SUITE Diorite and Monzodiorite [possibly including Gabbroic Rocks]	Massive, grey to black-and-white, plagioclase-porphyritic leucogabbro, diorite and monzodiorite. Shows a strong resemblance to parts of the Adlavik Intrusive Suite (see above).	Coarse to very coarse-grained, with large (5 cm) Plag megacrysts, ranging in shape from euhedral to rounded. Mafic minerals show interstitial to oikocrystic habit. Interstitial granophyric material.
43.0	Monzonite, Syenite and Quartz Syenite	Ranges from a grey to brown or buff Plag-porphyritic monzonite (similar to above) to pink or buff syenite and quartz syenite. Relict, mantled plagioclase xtals give "speckled-eggshell" texture.	Medium to coarse-grained, massive, ranges from porphyritic to seriate and (locally) equigranular. Interstitial Qz + K-fsp, local K-feldspar phenocrysts. Mafic minerals form euhedral or subhedral aggregates.
44.0	Syenite, Quartz Syenite, Granite and alkali-feldspar Granite 1625 +/- 50 Ma (Rb-Sr WR) (Brooks, 1982) 1650 +/- 10 Ma (U-Pb zircon) (Krogh et al., in prep.)	Dominated by homogeneous, pink, grey and buff-white, locally porph- yritic syenite to alkali-fsp granite. Plag-porphyritic variants resemble the above, but with small vestigial plagioclase phenocrysts only.	Generally fine to medium-grained, massive and K-feldspar porphyritic. Fine-grained equigranular rock types and quartz-feldspar porphyry occur locally. Rapid local grain size variations.
45.1 45.2 45.3 45.4 45.5 45.6	MONKEY HILL INTRUSIVE SUITE Monkey Hill Granite 1640 +/- 10 Ma (U-Pb zircon) (Krogh et al., in prep.) Round Pond Granite 1620 +/- 60 [K-Ar Bi] (Wanless et al., 1970) [For other plutons, see Figure 5.1]	All plutons are dominated by grey to buff or pink, locally slightly porphyritic, homogeneous, leuco- cratic biotite-chlorite monzogranite, granite and (locally) alkali-fsp granite. Also includes graphic leuco- granite and Qz-Fsp porphyry.	Generally fine to medium grained. Small, euhedral plagioclase crystals impart a "porphyritic" texture. Mineralized plutons are locally miarolitic and/or pegmatitic. Inclusions are rare, except near contacts. Tuffisite breccias suggest volatile exsolution and high level emplacement.
46.0	Witchdoctor Granite 1632 +/- 9 [U-Pb Zr] 1595 +/- 34 [Rb-Sr WR] (Brooks, 1982, 1983)	Homogeneous, leucocratic, white to pink, Bi-Ms granite to alkali-fsp granite located close to Benedict fault zone.	Generally medium to coarse-grained. Mostly equigranular, but locally K-feldspar porphyritic. Foliation defined by ribboned quartz.
47.0	Burnt Lake Granite 1548 +/- 90 [Rb-Sr WR] (MacKenzie and Wilton, 1988)	Dominated by homogeneous, white, pale grey to pink, leucocratic to alaskitic monzogranite and granite. Parts of the unit resemble fine- grained Witchdoctor Granite.	Generally fine to medium-grained, equigranular to locally porphyritic. Variably foliated, but invariably has a "sugary" appearance due to recrystallization; locally it is similar to metavolcanic country rocks.
48.0	Otter Lake - Walker Lake Granitoid 1647 +/- 2 Ma (U-Pb zircon) (Krogh et al., in prep.)	Dominated by compositionally variable grey to pink or green- white, two-feldspar porphyritic, biotite-hornblende quartz monzonite, granodiorite, monzogranite and granite. Melanocratic dioritic variants occur locally.	Generally medium to coarse-grained, massive, porphyritic to seriate in texture. K-feldspar phenocrysts are larger (3-5 cm) than coexisting Plag. Mafic minerals are interstitial, or form rounded clots. Unit locally has east-trending foliation.

Table 5.1 (continued).

Key Field Relationships	Mineralogy	Petrography
Gabbro cuts Upper Aillik Group, but is cut by monzogranite of Monkey Hill Intrusive Suite. Gabbro appears to be gradational with the diorite and monzodiorite (see below), but locally it includes angular diorite xenoliths. Gabbro appears to occur both above and below the diorite unit.	Plagioclase (An40-80; 30-75 %) Cpx (augite, 10-50%) Opx (Gabbronorite only, 5-20%) Hb (green or brown, 5-50%) Bi (red-brown, 5-20%) Qz + K-fsp (interstitial, 0-7%) Olivine (minor, 5-20% in Gabbronorite) Accessory Ap, Fe-Ox.	Complete range from fresh, well-preserved examples to altered rocks dominated by saussuritized Plag and secondary Actinolite - epidote. Hb commonly forms rims on Cpx, suggesting late (deuteric?) origin. Qz and K-fsp (where present) form interstitial granophyric material.
Appears gradational with gabbros at Adlavik Bay, yet contains gabbro xenoliths. Cut by net-veined mafic dykes and veins identical to those in gabbroic unit.	Plagioclase (An40-50; 40-65%) Qz (0-8%, interstitial with K-fsp) K-fsp (5-25%, locally abundant) Cpx + Hb + Bi (10-20% total) Opx (0-10%, in Plag and Cpx-rich variants.) Accessory Ap, Zr, Fe-Ox	Continuum from fresh Px-Bi bearing diorite to Hb-diorite to variably altered Plag-Act-Ep assemblages. Primary Hb in some variants, elsewh Hb forms rims on Cpx. Qz and K-fsp are interstitial (trapped liquid ?).
Appears to be gradational with dominant monzonite and syenite unit (see below). Interpreted to form lowermost (and/or marginal) facies of the Suite.	Qz (0-2%, interstitial habit) K-fsp (Mi, 5-20%, interstitial) Plag (An40-60; 50-80%, sauss.) Cpx +/- Opx (5-20% total) Hb + Bi (0-10% total) Olivine (0-10%, mostly relict) Accessory Ap, Fe-Ox.	Most examples contain serpentine-Fe-Ox patches, probably pseudo-morphs after olivine. Altered variants contain saussuritized Plag and Act-Ep-Sph-Chl aggregates.
Mafic and felsic end-members are similar to other units in Suite; relationship is probably gradational. This unit gives way to syenite and granite at high elevations.	Qz (0-10%, interstitial habit) Plagioclase (2 types, 30-60%) K-fsp (Mi, locally phenocrysts) Hb + Bi (5-15% total) Cpx (0-5%, commonly relict) Accessory Sph, Zr, All, Fl.	Clear igneous textures. Plag forms zoned phenocrysts rimmed by fresh Plag and/or K-feldspar. Cpx occurs in mafic variants, rimmed by Hb. Most K-fsp (+/- Qz) interstitial. Sphene locally forms cores to Hb.
Least differentiated examples are similar to the dominant monzonite to syenite unit. Mostly restricted to high elevations, but occurs sporadically in other units. Relationship gradational ?	Qz (5-15%, up to 30% locally) K-fsp (50-80%) Plag (10-35%) Bi + Hb (3-8% total, Bi > Hb) Accessory Sph, Zr, Fl	Qz and K-fsp form graphic intergrowths with interstitial habit. Mi pheno-crysts have relict simple twinning. Local plagioclase phenocrysts are embayed and resorbed. Hb locally shows poikilitic habit.
Monkey Hill Granite intrudes the Upper Aillik Group and Kennedy Mountain Suite. Duck Island Granite intrudes the Long Island Quartz Monzonite. Little Monkey Hill Granite cuts Adlavik Intrusive Suite.	Qz (20-35%, interstitial habit) Plag (An15-25; 30-50%) K-fsp (Mi, 30-50%) Bi + Chl (0-4% combined) Epidote (primary?) Ms (minor) Gnt (Kidlaluit granite only)	Igneous textures well preserved. K-fsp is mostly a groundmass phase; in equigranular variants it forms graphic intergrowths with quartz. Bi is pervasively altered to Chl; many rocks contain only Chl.
Contacts are not exposed. This unit is mineralogically and compositionally akin to the Burnt Lake Granite (see below).	Qz (25-40%) K-fsp (Mi, 40-70%) Plag (An20, 10-25%) Bi + Ms (1 - 5% total, Bi > Ms) Hb (relict) Gnt (minor, << 1%) Chl, Ep, Sph, All	Foliation defined by aggregates of Bi + Ms, Bi altered to Chl. Pink garnet is rare; commonly broken and cracked. Epidote intergrown with Hb + Bi.
Intrudes felsic volcanic rocks of the Upper Aillik Group, but locally appears gradational. Mineralogically and compositionally similar to the Witchdoctor Granite.	Qz (20-40%) K-fsp (Mi, 25-45%) Plag (20-50%) Bi + Ms (0-5% total, Bi > Ms) Accessory All, Gnt (rare) , Sph.	Variably recrystallized; relict porphyritic textures preserved. Ms is intergrown with Bi, and also occurs as very fine-grained (secondary ?) material.
Intrudes felsic volcanic and meta-sedimentary rocks of Upper Aillik Group. Granites correlated with this unit intrude Bruce River Group. In fault contact with Melody Granite and Archean gneisses.	Qz (15-30%) K-fsp (Mi, 30-50%) Plag (An25-40, 25-50%) Bi + Hb (3-8%, Bi > Hb) Cpx (rare, relict) Abundant Sph (up to 2%) Accessory All, Zr, Ap	Igneous textures generally well-preserved. Qz is interstitial. Mi phenocrysts are fine perthite, with local rims of sodic Plag. Plag phenocrysts have zoned, saussuritized centres. Biotite has green colour. Sphene very prominent; euhedral or interstitial habit.

5.1 GEOLOGY AND PETROLOGY

Locations and extent of principal Labradorian plutonic units are indicated in Figure 5.1. Key field and petrographic characteristics are summarized in table 5.1.

5.1.1 Adlavik Intrusive Suite

Definition and Distribution

This suite includes layered gabbroic and dioritic rocks exposed at Adlavik Bay and Big River valley, and also as a number of isolated bodies, of which the most important is at Pamiulik Point (Figure 5.1). The type locality at Adlavik Bay is referred to below as the "main body".

The main body was defined initially by Gandhi et al.(1969) and Stevenson (1970), and termed "Adlavik Complex", which was later modified to Adlavik Intrusive Suite by Gower (1981). A U-Pb zircon date of 1649 +/- 1 Ma was obtained from a potassic monzodiorite at Adlavik Bay (Krogh et al., in prep.). Gower et al. (1982) summarize previous K-Ar dates (Gandhi et al., 1969; Wanless et al., 1970) from minor intrusions possibly related to the suite; these range from 1660 to 1540 Ma. A postulated link to the rocks now termed Numok Intrusive Suite (Kerr, 1986) has since been disproved by ca. 1800 Ma U-Pb zircon ages from the latter (see Chapter 4).

The main body is a very complex, layered, multi-component intrusion that could easily form an extended Ph.D. topic by itself. The scale of mapping and sampling in this regional project is inadequate to resolve all of the problems inherent in its geometry and stratigraphy, and the following account is undoubtedly an oversimplification.

Mafic Plutonic Rocks

These correspond to unit 13 of Gower (1981) and unit 22a of Gower et al.(1982), and exhibit great variety in composition and texture. Clark (1973) mapped the northern fringe of the main body, and outlined five subunits or "facies". These have been revised and augmented during this project (Kerr, 1987b; Figure 5.2), and are used as a framework for description. The following descriptions apply mostly to the main body; other areas of the suite are dominated by melagabbro and leucogabbro facies. Plates 5.1 and 5.2 illustrate various field characteristics of mafic rocks within the Adlavik Intrusive Suite.

Marginal Gabbro and Diabase : This is best exposed in the Big Bight area (Figure 5.2), but occurs locally around the western edge of the main body, where it forms a thin (usually < 5 m) discontinous margin against the Upper Aillik Group country rocks. It is a fine to medium-grained, equigranular, grey rock with variably diabasic texture. In the Big Bight area it contains primary acicular hornblende and is closer to diorite in composition. In parts of the mafic cumulate facies, it occurs as rounded xenoliths or pillows in coarse gabbro. These agmatites probably record disruption of a chilled margin by later magma, also suggested by Gower (1981) for a similar texture at Pamiulik Point.

Mafic Cumulate Facies : This corresponds partly to the rhythmic layered facies of Clark (1973). It is well-exposed at Big Bight, where it forms the base or side of the intrusion. It is also present locally within the dominant leucogabbro facies and the diorite unit. Rhythmic layering,

LABRADORIAN PLUTONIC ROCKS

| | 9 | Monkey Hill Intrusive Suite (Little Monkey Hill Granite) |

ADLAVIK INTRUSIVE SUITE

| | 4 | Diorite and Monzodiorite |

	3	(d) Leucogabbro Facies
	3	(c) Melagabbro Facies
	3	(b) Mafic Cumulate Facies
	3	(a) Marginal Gabbro and Diorite

POST-TECTONIC MAKKOVIKIAN PLUTONIC ROCKS

| | 7 | Big River Granite |

| | 8 | Strawberry Intrusive Suite (Poodle Pond Granite) |

| | 10 | Lanceground Intrusive Suite |

| | 5 | (a) Numok Intrusive Suite (Agmatitic Border) (b) Numok Intrusive Suite (Monzonite - Quartz Monzonite) |

| | 6 | Numok Intrusive Suite (Syenite - Quartz Syenite) |

SYN-TECTONIC MAKKOVIKIAN PLUTONIC ROCKS

| | 2 | Manak Island Granitoid |

SUPRACRUSTAL ROCKS

| | 1 | Upper Aillik Group (Undivided) |

SYMBOLS

Geological contact (approximate, inferred)

Igneous layering or foliation

Penetrative foliation

Fault (inferred)

☆ Location of pegmatitic gabbro-diorite material containing minor sulphide

Figure 5.2. Simplified geological map of the main body of the Adlavik Intrusive Suite. Partly after Clark (1973), Gower et al.(1982) and Kerr (1988b).

– 164 –

graded bedding, and cross-bedding are well developed in
these rocks. At Big Bight, they form at least two irregular
cyclic units (Figure 5.3). Each cycle commences with
coarse-grained ultramafic rocks, dominated by amphibole and
biotite, but with a relict pyroxenite mineralogy. These are
interlayered with and overlain by layered gabbro and
gabbronorite, where hornblende crystals with a "stubby"
habit (after pyroxene ?), containing augitic cores, define
rhythmic layering and graded bedding. The upper portion of
each cycle consists of very coarse-grained amphibole-
bearing "pegmatites" (pegmatite facies; see below) that
also occur as irregular, diffuse, veins and pods that
disrupt the underlying cumulates.

Melagabbro Facies : The mafic cumulate facies is
overlain in the Big Bight area by massive, dark grey to
black, coarse-grained, melanocratic rocks (termed "massive
diabase facies" by Clark, 1973, but not generally
diabasic), which in turn grade upward into the dominant
leucogabbro facies. The melagabbro generally contains less
than 50% plagioclase; it is locally a gabbronorite, but in
most areas mafic phases have been transformed to· amphibole
(see below). It is locally strongly epidotized around
networks of fractures or veinlets.

Leucogabbro Facies : This areally dominant facies is a
grey to white or purple-brown, coarse to very coarse-
grained, leucogabbro or leucogabbronorite. It is
distinguished from the melagabbro by a higher plagioclase
content (up to 70%), but the two are gradational. It
contains interstitial (locally oikocrystic) mafic minerals
and locally has a magmatic foliation defined by plagioclase
alignment. Diffuse mafic mineral accumulations and thin
zones of rhythmic layering provide evidence of cumulus
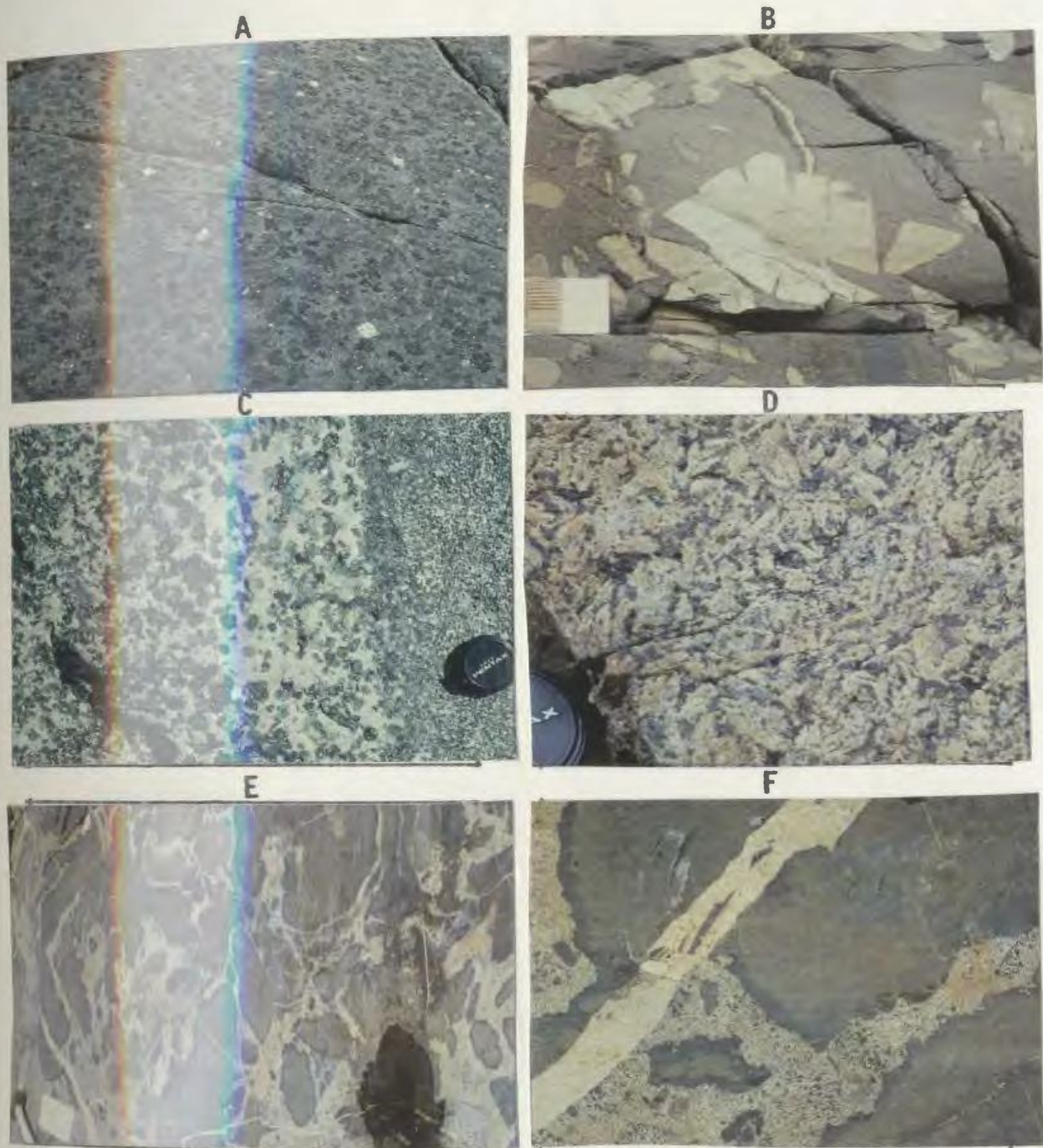
Plate 5.1. Features of mafic rocks in the Adlavik Intrusive Suite (see also Plate 5.2). (a) Mafic cumulate with amphibole megacrysts up to 5 cm diameter, containing augite cores, Pamiulik Point area. (b) Stoped blocks of diorite in melanocratic gabbro, Adlavik Bay. (c) Graded bedding in mafic cumulate, Big Bight, tops to right of photo. (d) Coarse "diabasic" texture, probably a plagioclase cumulate, coastline south of Manak Bay. (e) Composite diabase body intruding leucogabbro facies, Adlavik Bay. Note chilled margins on diabase lozenges. (f) Detail from same locality, white vein is about 5 cm wide. Note disruption of chilled margins by grey, intermediate material.

processes, and it is viewed as a plagioclase cumulate. Leucogabbronorite is restricted to the northern margin and inner part of Adlavik Bay, but many samples retain only relict primary mineralogy (see below), and it is therefore difficult to assess the original extent of orthopyroxene and olivine-bearing rocks.

This facies is homogeneous, except for locally voluminous cross-cutting composite diabase and gabbroic pegmatite (see below). In one locality it includes angular, stoped blocks that resemble the diorite unit (described below .

Gabbroic Pegmatite Facies : This consists of coarse-grained, generally quartz-free, gabbroic and dioritic "pegmatite", containing acicular hornblende (locally as unusual hollow crystals), and variable amounts of K-feldspar. It is associated with the mafic cumulate facies (see above), and occurs as sporadic masses (rarely more than 400 m^2) that intrude all the above and the diorite unit. In the mafic cumulate facies, it is probably a local volatile-rich residual magma formed by crystallization of the underlying cumulates. It is suggested that it forms a late phase formed by the operation of similar processes on an intrusion-wide scale.

Composite Diabase Facies : Fine to medium-grained diabase forms numerous outcrop-scale dykes, veins and irregular masses that intrude and disrupt mafic and diorite units. These have a chaotic internal structure, where diabase is intruded and disrupted by grey, intermediate material that appears to originate in the local wall rocks. Chilled margins are present around individual diabase "pillows", but these are cut and net-veined by this intermediate material. Preferred orientation of diabase
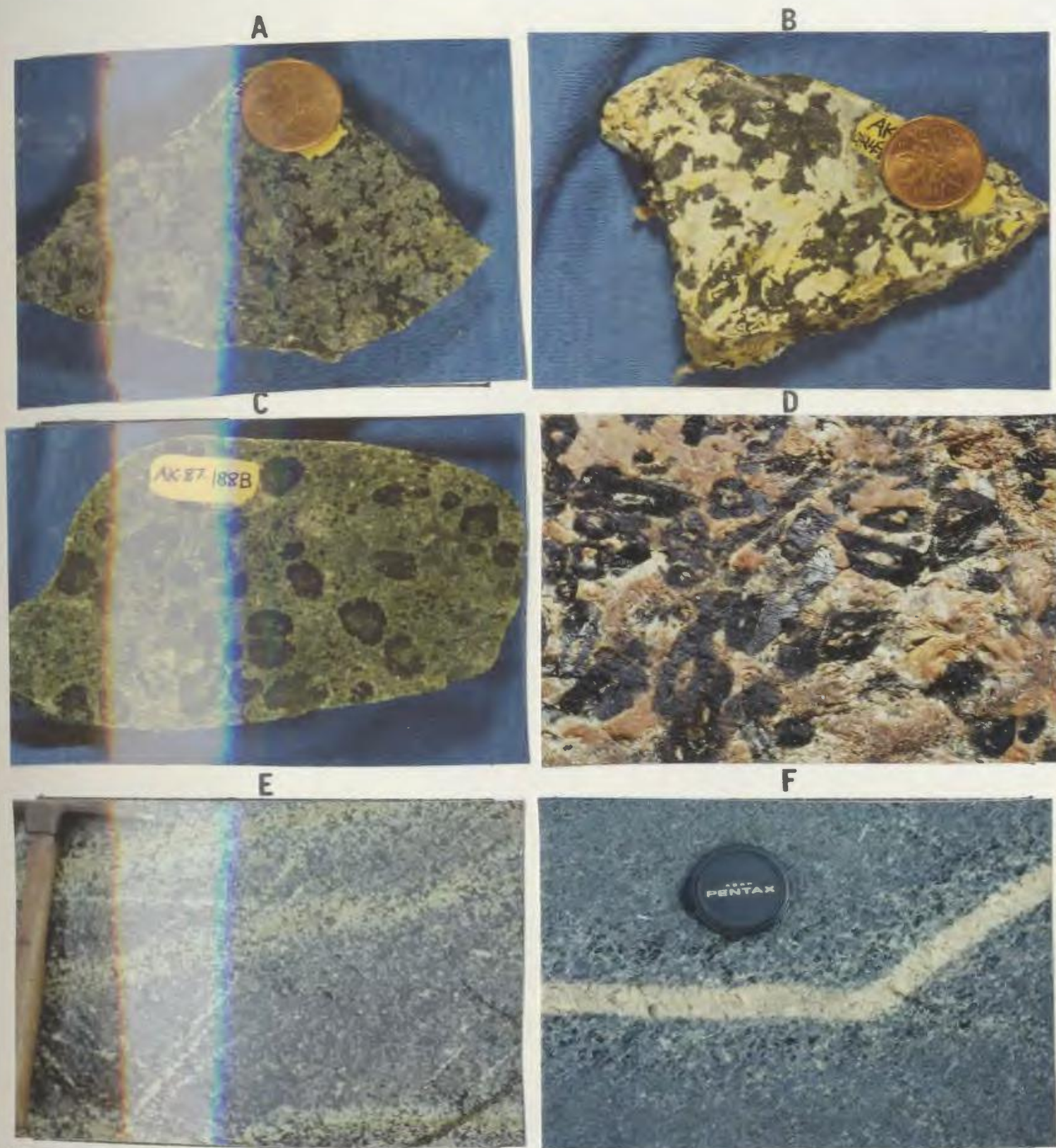
Plate 5.2. Features of mafic rocks in the Adlavik Intrusive Suite (see
also Plate 5.1). (a) and (b) Typical plagioclase-cumulate leucogabbro
samples. (c) Amphibole phenocrysts (after pyroxene) in a fine-grained
variant from Big Bight, note cores (altered augite). (d) Amphibole-
bearing pegmatite, with unusual, hollow hornblende crystals up to 2 cm
diameter (cross-section), Adlavik Bay. (e) Pervasive zones of
epidotization in melagabbro facies, Big Bight. (f) Amphibolitization
of gabbro around thin felsic veinlet, Jacques Island. Slabs stained
for K-feldspar.

lozenges in some areas suggests that these were zones of flow, and they are interpreted as conduits through which mafic magma batches ascended to higher parts of the intrusion. They were probably emplaced into hot, partly consolidated cumulates that contained residual liquid capable of mobilization and interaction with ascending mafic magma. Their presence in the diorite unit indicates that multiple batches of mafic magma were emplaced at Adlavik Bay, and that diorite is not the youngest component.

Petrographic Features : Mafic rocks of the Adlavik Intrusive Suite range from fresh variants where plagioclase, pyroxene and biotite are the dominant minerals to altered variants dominated by hornblende, saussuritized plagioclase and actinolite. Samples that lie between these extremes commonly contain hornblende as mantles on pyroxene crystals, suggesting that it is a late primary phase or a deuteric alteration product. In hydrated variants, clinopyroxene (± orthopyroxene) occurs only locally as relict cores in hornblende. Red biot : is present in hornblende-free rocks, and is probably part of the primary assemblage.

This mineralogical continuum is interpreted to reflect variations in the water content of the magma during crystallization (c.f. Clark, 1973). Although some pyroxene-free rocks (especially gabbroic pegmatites and parts of the diorite unit, see below) contain euhedral, primary hornblende, it is suggested that most were modified extensively by late-magmatic or deuteric effects. In some areas, amphibolitization is concentrated around fractures or thin felsic veinlets, indicating that at least some transformation was post-crystallization.

Fresh gabbronorite variants contain variable amounts of pleochroic hypersthene, and fresh to locally relict olivine, commonly mantled by orthopyroxene aggregates. Olivine does not occur widely in orthopyroxene-free rocks, but many are olivine-normative (see 5.2.2).

Ultramafic rocks, and associated mafic cumulates, contain large (up to 10 cm) megacrysts or crystal aggregates of amphibole with cores of clinopyroxene. They contain abundant pale (Mg-rich?) biotite (possibly phlogopite), and were probably originally biotite-pyroxenites.

Diorite and Monzodiorite

The most extensive area of this unit is in the main body (Figure 5.2), but similar rocks occur at Pamiulik Point and East Micmac Lake. It is more homogeneous than the mafic component of the Adlavik Suite, but locally resembles the most leucocratic gabbroic variants. The dominant rock type is a pale brown to pink or yellow-weathering, coarse-grained, equigranular to plagioclase porphyritic, pyroxene - hornblende - biotite or two-pyroxene diorite, quartz diorite or monzodiorite (Table 5.1; Plate 5.3).

At Adlavik Bay, the diorite appears to be gradational with adjacent plagioclase cumulates. However, it also includes angular xenoliths of gabbro and mafic cumulate indicating that it is younger than some of the mafic rocks.

Discontinous mafic mineral layers, primary foliations defined by plagioclase alignment, and thin (< 10 m) zones of mafic cumulates occur locally. The unit is cut by the composite diabase facies, and zones of coarse amphibole-feldspar pegmatite; the latter also occurs as isolated patches within coarse diorite that probably represent local volatile-rich pockets.
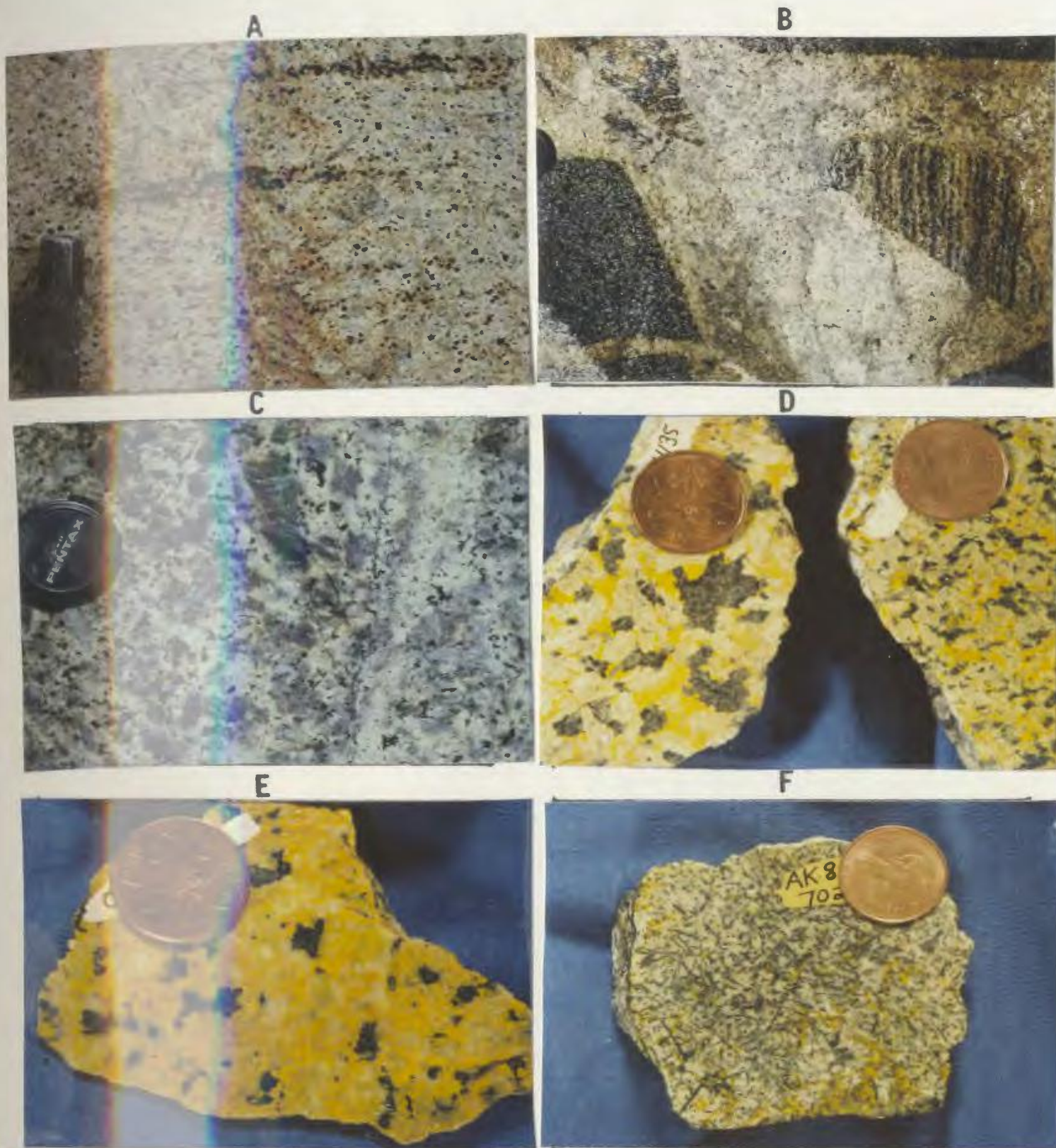
Plate 5.3. Features of the dioritic unit in the Adlavik Intrusive Suite. (a) Typical homogeneous diorite, with wispy mafic mineral layers suggesting cumulus processes, Adlavik Bay. (b) Xenoliths of leucogabbro and cumulate-layered gabbro (layered xenolith about 20 cm diameter) in diorite, Adlavik Bay. (c) Coarse-grained, plagioclase-rich variant, probably a plagioclase cumulate, Adlavik Bay. (d) Typical examples of diorite unit, Adlavik Bay, note interstitial K-feldspar. (e) Monzonitic to syenitic variant of unit. (f) Fine-grained, marginal, diorite with acicular hornblende, Big Bight area. Slabs stained for K-feldspar

As in the mafic rocks, there is a continuum from
near-anhydrous variants to rocks which lack pyroxene and
contain euhedral, probably magmatic hornblende. Red-brown
biotite is present in most examples, and its presence
appears independant of amphibole content. K-feldspar and
quartz are interstitial and late. A few plagioclase-rich
diorites contain both hypersthene and augite, suggesting a
possible link to gabbronoritic variants of the mafic
sequence.

Geometry and Stratigraphy of The Adlavik Bay Layered Intrusion

There are wide variations in primary layering attitudes
within single outcrops around Adlavik Bay. Reconstruction
of the geometry and stratigraphy of the intrusion is thus
very difficult. There is also no guarantee that layering
represents the same reference orientation in all locations,
or that all components were originally conformable; in
fact, field relationships suggest that there are probably
also internal intrusive contacts.

Layering attitudes around Adlavik Bay indicate,
however, that the diorite unit is at least partly overlain
by mafic rocks (assuming that their mutual contact is
parallel to layering in both). A possible interpretation
(Figure 5.4) is that the diorite is associated with a
lower, gabbronoritic sequence that is overlain (perhaps
"unconformably") by gabbro and leucogabbro. Contrasts in
normative mineralogy (see 5.2.2) also indicate that there
are spatially discrete gabbronorite and gabbro sequences.
It must be stressed this is only one of a number of
possible interpretations, and that space does not permit
discussion of all. The composite diabase facies is
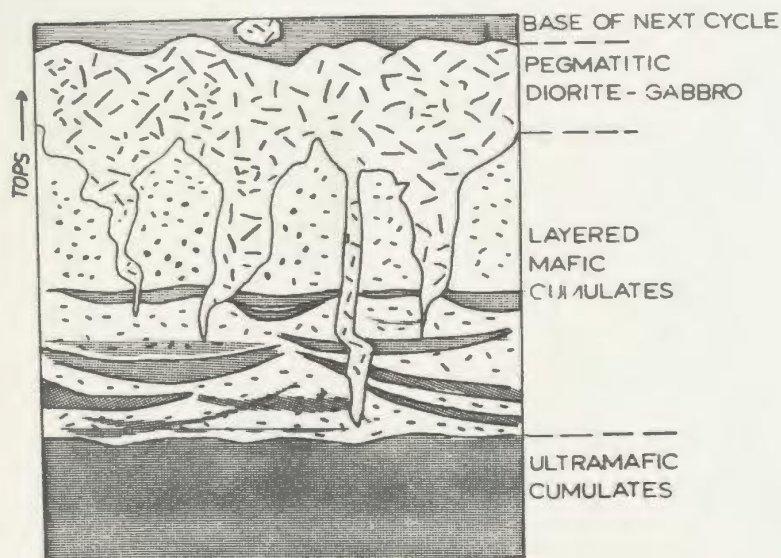
Figure 5.3. Schematic illustration of cyclic units in the Mafic Cumulate Facies in the Big Bight area, at the northern margin of the main Adlavik Bay intrusion.
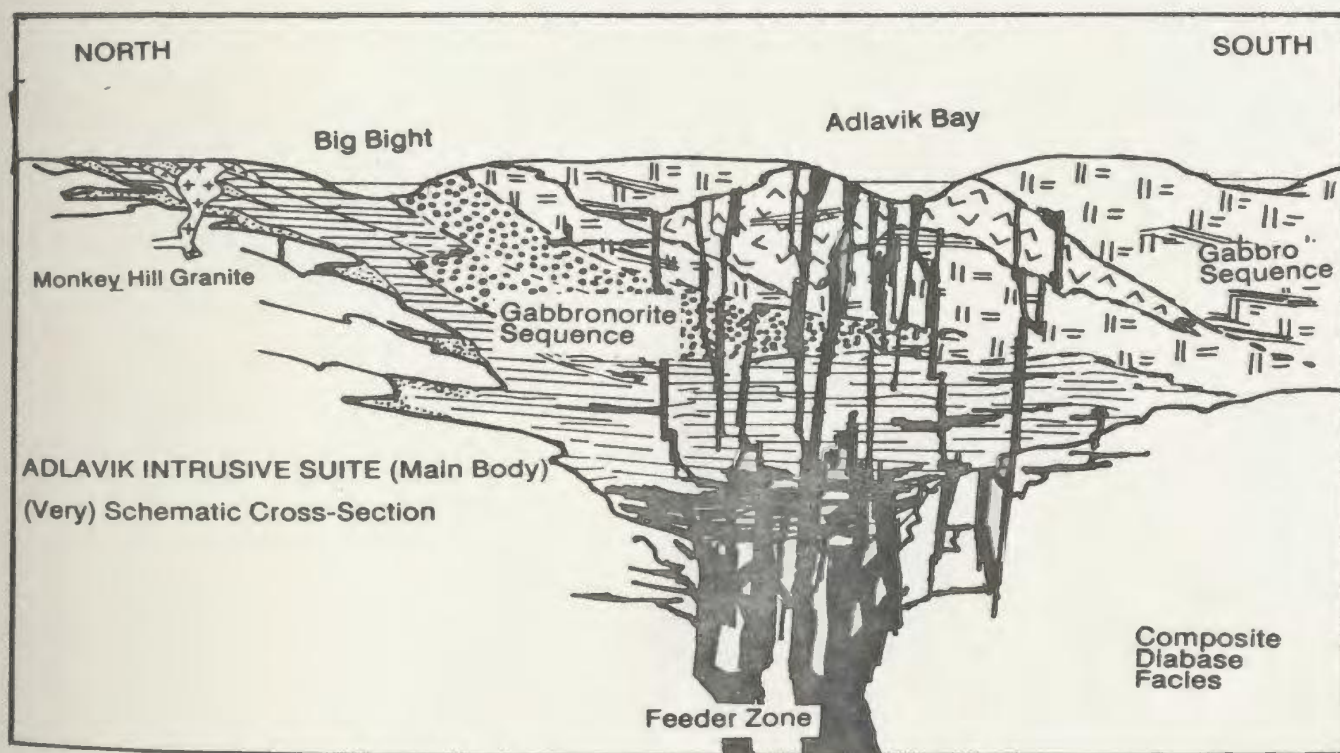
Figure 5.4. Schematic, interpretative cross-section of the main body of the Adlavik Intrusive Suite. See text for discussion.

(Legend as for Figure 5.2)

interpreted as the feeder system for higher parts of the intrusion, and the pegmatite facies as residuum from the crystallization of individual batches of magma.

5.1.2 Mount Benedict Intrusive Suite

Definition and Distribution

Mount Benedict Intrusive Suite is a new name introduced for compositionally varied rocks exposed in the Benedict Mountains (Figure 5.1). The term is not synonymous with "Benedict Mountains Intrusive Suite", introduced by Gower (1981) as a general label for intrusive rocks throughout this area. It is recommended that this older term be abandoned, as it includes both Makkovikian and Labradorian plutonic rocks, which cannot be directly related. The three units of the Mount Benedict Intrusive Suite correspond generally to textural variants described by Gower (1981) in his unit 21. They form a continuum from diorite and monzodiorite through monzonite and syenite to granite (s.s.) (Table 5.1; Plate 5.4). The overlap between them suggests that they are closely related and probably mutually gradational.

The southern boundary of the Mount Benedict Suite is marked by a narrow belt of strongly deformed felsic volcanic rocks that is probably bounded by faults associated with the Benedict Fault system. In the east, it is bounded by the Tukialik granite of the Strawberry Intrusive Suite, which it is presumed to intrude. The map pattern suggests dextral displacement across a fault cutting through the suite, which is here interpreted as the continuation of the Adlavik Brook Fault zone. The nature of the western contact with the volcanic rocks east of Stag Bay is unknown.

Geochronology : Brooks (1982) obtained a Rb-Sr whole rock isochron suggesting an age of 1625 +/- 50 Ma for syenite at Mount Benedict, but alluded to possible disturbance. U-Pb zircon data from a nearby locality (Krogh et al., in prep.) are slightly discordant, and indicate an age of 1645 ± 10 Ma, or a maximum age of 1668 Ma assuming a 1000 Ma lower intercept. The Mount Benedict and Adlavik Suites are thus of essentially the same age.

Gabbro and Diorite

Gabbro and diorite are restricted mostly to the southwestern edge of the suite, but occur sporadically within the other two units. An area of mafic cumulate, melagabbro and monzodiorite exposed at Pamiulik Point (grouped here as Adlavik Intrusive Suite) may also be part of this unit. Gower (1981, pers.comm., 1988) states that there is no obvious structural break between these rocks and syenite to the south. As discussed subsequently (5.3), the similarity between the least evolved rocks of the Mount Benedict Suite and parts of the Adlavik Suite suggests a genetic link between them.

The unit consists of plagioclase-porphyritic pyroxene (± olivine) - bearing gabbro, leucogabbro and diorite, locally transitional to monzonite. Plagioclase alignment, and the oikocrystic habits of mafic minerals, indicate a cumulate origin. Several samples contain equant serpentine-iron oxide clots with cores of fresh olivine. Fresh examples contain pleochroic hypersthene, and a purple to brown titanaugite with prominent exsolution lamellae (probably an inverted pigeonite). Red-brown biotite is also common. Altered variants consist of saussuritized

- 176 -

Plate 5.4. Features of the Mount Benedict Intrusive Suite. A
continuum of compositions from plagioclase cumulate (a), through
diorite (b), monzonite - syenomonzonite (c), syenite (d) to quartz
syenite (e). Note persistence of vestigial plagioclase phenocrysts in
all but.(e). (f) A combination of textures, with plagioclase crystals
entrained in syenite. All samples from Mount Benedict - Jeanette Bay
area. Slabs stained for K-feldspar.

plagioclase, hornblende and actinolite (± epidote, sphene). This unit has many petrographic similarities to gabbro and diorite of the Adlavik Intrusive Suite.

Monzonite, Syenomonzonite and Syenite

This unit forms a compositional and textural continuum from plagioclase-porphyritic, pyroxene monzodiorite to coarse-grained, biotite-hornblende syenite containing only minor plagioclase (Table 5.1; Plate 5.4). The dominant rock type is a grey to buff, seriate to porphyritic, monzonite, quartz monzonite or syenomonzonite (i.e. potassic monzonite). It is commonly plagioclase- porphyritic, although the contrast in grain size between groundmass and phenocrysts is slight. The groundmass consists of a medium-grained aggregate of quartz, K-feldspar and mafic silicates. Gower (1981) termed this "speckled-eggshell texture", and suggested that the plagioclase phenocrysts had been resorbed by the magma. In some samples, plagioclase phenocrysts have K-feldspar rims, and resemble pseudorapakivi feldspars such as those in the Big River Granite (see Chapter 4). Speckled-eggshell texture is present throughout the unit, but is developed most widely in monzonite and syenomonzonite; syenitic rocks contain only scattered vestigial plagioclase phenocrysts.

Plagioclase phenocrysts are zoned and saussuritized, whereas groundmass material forms clear laths. Interstitial quartz, or graphic quartz - K-feldspar micropegmatite, is commonly present. Relict clinopyroxene occurs in the cores of euhedral hornblende crystals in mafic variants. Locally, hornblende crystals have sphene cores, suggesting "early" crystallization of the latter.

Syenite, Quartz Syenite and Granite

This unit is prevalent on the higher peaks of the Benedict Mountains, and is best exposed around Mount Benedict. It also occurs sporadically within the dominant monzonite-syenite. Partial restriction to higher elevations suggests that it may be a roof facies (Gower, 1981) or, alternatively, the uppermost portion of a compositionally layered body. The latter interpretation is supported by systematic geochemical changes with elevation (see 5.3).

It is dominated by homogeneous, pink, grey or buff colored, locally porphyritic, fine to medium-grained, leucocratic, syenite, quartz syenite or granite. Potash feldspar is a common phenocryst phase, but vestigial plagioclase phenocrysts and speckled-eggshell texture are present locally. In one location, it contains large (2 cm), embayed plagioclase crystals that appear to have been entrained in syenitic magma. The unit locally grades into a feldspar or quartz-feldspar porphyry of subvolcanic aspect, suggesting a high level of emplacement.

Graphic quartz-microcline intergrowth textures in the groundmass, and coarse perthite phenocrysts, suggest epizonal characteristics. Biotite is the dominant mafic phase, forming subhedral single crystals or aggregates with associated (usually relict) hornblende. Accessory minerals (sphene and zircon) are prominent, and fluorite occurs as interstitial material and discordant veinlets.

5.1.3 Monkey Hill Intrusive Suite

Definition and Distribution

Monkey Hill Intrusive Suite (Kerr, 1988) is a new name proposed for several discrete, small, epizonal plutons

located in the Kaipokok Bay - Makkovik Bay area (Figure
5.1). The type locality (referred to below as the "main
body" is at Monkey Hill, near Makkovik. All of these
plutons intrude the Upper Aillik Group, and all consist of
similar fine-grained, leucocratic monzogranite and granite
(Table 5.1; Plate 5.5). They are probably small stocks or
cupolas connected to a larger body at depth. In a
discussion of potential specialized granitoids, Kerr (1988)
included the similar Witchdoctor and Burnt Lake granites
(see below) with this suite. In view of the distance
between these units and the type locality, and some
differences in petrography, these are here treated
separately. The Monkey Hill Intrusive Suite corresponds to
parts of Units 28a and 28b of Gower et al. (1982).

Geochronology : Wanless et al.(1970) obtained a K-Ar
age of 1625 ± 60 Ma from the Round Pond Granite. A Rb-Sr
isochron of 1520 ± 35 Ma from this body (Wilton and
MacDougall, pers. comm., 1988) is probably disturbed by
hydrothermal activity related to mineralization. U-Pb
zircon data from the main body (Krogh et al., in prep.) are
discordant, but suggest an imprecise age of ca. 1640 ± 10
Ma. They are colinear with zircon data from other
Labradorian plutonic rocks, suggesting that all are of
broadly similar age.

Lithology and Field Relationships

.

Field Relationships : The <u>Monkey Hill Granite</u> is a
small (< 50 km^2) pluton that intrudes the Upper Aillik
Group and foliated granitoid rocks of the Kennedy Mountain
Intrusive Suite. The <u>Duck Island Granite</u> is a small stock
or cupola restricted to a small islet in Mark's Bight;

Plate 5.5. Features of the Monkey Hill Intrusive Suite. (a) Two phases of the Monkey Hill Granite; the dominant pink granite cuts a darker, grey-brown phase, Gull Island, Makkovik Bay. (b) Vein correlated with Little Monkey Hill Granite cutting gabbro of the Adlavik Intrusive Suite, Big Bight (large gabbro block about 30 cm across). (c) Tuffisite breccia, with clasts of miarolitic granite and biotite-chlorite matrix, Makkovik Bay. (d) and (e) Typical Monkey Hill Granites, from the main body. (f) Molybdenite-bearing, slightly pegmatitic phase of the Duck Island Granite, Duck Island.

however, numerous veins and sheets of similar material
intrude the Long Island Quartz Monzonite within a 2 km
radius of the island. The Round Pond Granite (described by
MacDougall and Wilton, 1987, and MacDougall, 1988),
consists of two small bodies that intrude the Upper Aillik
Group, and are associated with hydrothermal alteration and
mineralization. The Little Monkey Hill Granite forms a
prominent peak about 12 km east of the main body, and
intrudes the Upper Aillik Group; dykes and veins associated
with this body also cut mafic rocks of the Adlavik
Intrusive Suite. The Bent's Cove Granite intrudes
metasedimentary rocks of the Upper Aillik Group. The
Kidlaluit Granite occupies most of Kidlaluit Island, and
includes large blocks of coarse gabbro that resemble those
of the Adlavik Suite. Contacts of all bodies are sharp,
intrusive interfaces characterized by stoping and
net-veining of the country rocks. The relationship with the
Adlavik Suite gabbro suggests that the Monkey Hill
Intrusive Suite is younger than ca. 1650 Ma.

Lithology and Petrology : All members of the Suite
are dominated by grey to buff or pink, fine to medium
grained, faintly porphyritic, leucocratic monzogranite,
granite and (locally) alkali-feldspar granite (Table 5.1;
Plate 5.5). They are homogeneous, and lack inclusions
except near contacts. The Duck Island and Round Pond
Granites, and parts of the Kidlaluit Granite, are locally
pegmatitic and/or miarolitic. The main body at Monkey Hill
contains xenoliths of a darker-coloured phase on Gull
Island, but is otherwise remarkably homogeneous over 900 m
of vertical relief. At the northern end of Kidlaluit
Island, an earlier grey phase is cut by the dominant
pinkish granite. "Tuffisite" breccias consisting of granite

clasts in a bictite-rich matrix are locally exposed around
Makkovik Bay, and suggest exsolution of dissolved
volatiles. Shallow emplacement is also suggested by the
local occurrence of a very fine-grained feldspar porphyry
of subvolcanic appearance in the main body, Bent's Cove
Granite, and associated with the Duck Island Granite.

The circular-shaped body northeast of the Duck Island
granite consists of graphic micropegmatite that forms a
network of sheets and veins intruding the Upper Aillik
Group. Although petrographically atypical of the suite, it
is grouped with it on the basis of proximity to three other
members.

Petrographic Characteristics : Plagioclase forms
small (up to 5mm), euhedral to subhedral laths that appear
to have crystallized early and, although similar in size to
other grains, impart a "porphyritic" or "speckled"
appearance. They have saussuritized cores, and are locally
zoned. Quartz is interstitial or graphically intergrown
with microcline. Green or green-brown biotite forms
dispersed crystals or aggregates, and is altered to
chlorite along cleavage traces. In many samples, chlorite
is the dominant mafic mineral. Epidote is common in
chlorite-bearing variants, and locally displays an
interstitial habit suggesting that it may have been a
primary magmatic phase. Garnet has been observed only at
the northern end of the Kidlaluit Granite.

5.1.4 Witchdoctor and Burnt Lake Granites

The Witchdoctor and Burnt Lake Granites occur in the
southwest of the study area, between the Benedict Fault
zone and an area of Upper Aillik Group volcanic rocks.

The two units are similar in many respects, and the Burnt Lake Granite is interpreted as a fine-grained marginal or roof phase of the Witchdoctor Granite.

Witchdoctor Granite

This is poorly exposed, and its contact relationships are unknown. It corresponds to Unit 26e of Gower et al. (1982), and to part of the "Walker Lake Granite" of BRINCO geologists, which also included parts of the Otter Lake - Walker Lake Granitoid (see below). It was previously described as hornblende monzonite and granodiorite (Bailey, 1979; Gower et al.,1982), but this description largely reflects its supposed correlation with the quite different granitoid rocks to the west. Brooks (1983) dated this unit at 1595 ± 34 Ma (Rb-Sr, whole rock) and 1632 ± 9 Ma (U-Pb, zircon). It is dominated by pink to white, medium to coarse grained, variably foliated, leucocratic biotite and biotite - muscovite monzogranite to alkali-feldspar granite (Table 5.1; Plate 5.6). Most examples are homogeneous and equigranular, but recrystallization and deformation are widespread, and local east-trending fabrics are present.

Quartz is extensively recrystallized and forms elongate ribbon-like aggregates, although it locally retains a vestigial interstitial habit. Green-brown biotite is intergrown with lesser amounts of muscovite, forming aggregates parallel to foliations. Relict hornblende occurs locally in muscovite-poor variants, and chlorite occurs locally as an alteration product of biotite. Pale pink garnet is a minor constituent of several samples.
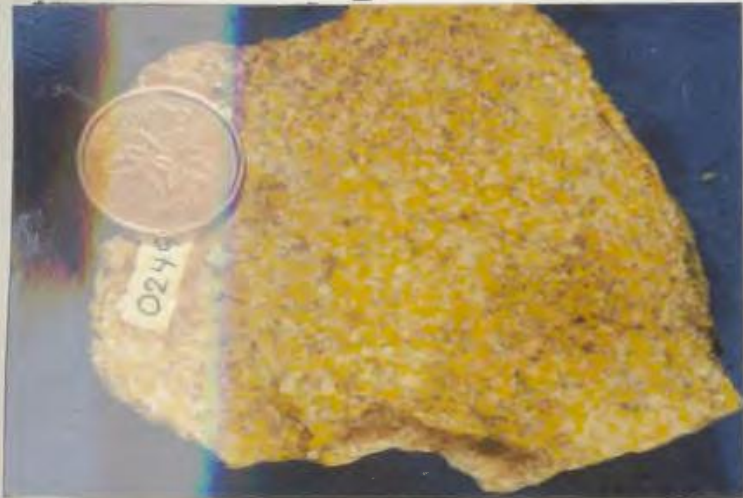
Plate 5.6. Features of the Witchdoctor and Burnt Lake Granites. (a) and
(b) Typical examples of the Witchdoctor granite, showing variable
recrystallization and deformation, Witchdoctor Lake area. (c) and (d)
Foliated and unfoliated Burnt Lake Granites, Burnt Lake area. (e)
Miarolitic Burnt Lake granite, adjacent to Burnt Lake moybdenite
showing. Slabs stained for K-feldspar.

Burnt Lake Granite

The Burnt Lake Granite is dominated by white to pale grey or pink, fine to medium grained, equigranular, leucocratic monzogranite, granite and (locally) alkali feldspar granite (Table 5.1; Plate 5.6).

Bailey (1979) described its contacts with the Upper Ailik Group as gradational, a reflection of the similarity between fine-grained granite and sugary, recrystallized rhyolite. However, MacKenzie and Wilton (1987) described sharp intrusive contacts from several localities. Rb-Sr data presented by MacKenzie and Wilton (1988) give a 1548 +/- 90 Ma errorchron, which they suggested to be disturbed by Grenvillian events. This could, however, also be interpreted as a reflection of post-crystallization hydrothermal activity (c.f. Walraven et al., 1986). Disseminated Mo mineralization is present in the contact zone of the granite, and it has also been linked to uranium - base metal mineralization in adjacent country rocks (MacKenzie and Wilton, 1987).

Most samples are recrystallized, and original igneous textures, except for relict microcline phenocrysts, are not readily discerned. Muscovite occurs both as intergrowths with biotite flakes of a similar size range, and as fine-grained fibrous aggregates of secondary appearance. It is absent in the more melanocratic variants. Minor garnet is present locally, but is less common than in the Witchdoctor Granite.

5.1.5 Otter Lake - Walker Lake Granitoid

This is a regionally extensive granitoid unit in the southwest of the study area (Figure 5.1), which extends for 50-75 km beyond the western edge. It corresponds to unit 32

of Ryan (1984), which he grouped with spatially associated muscovite-biotite granites (Crooked River Granite) to form the Nipishish Lake Intrusive Suite. The Crooked River Granite does not outcrop within the study area. Descriptions below apply only to quartz monzonite, monzogranite and granite within the study area.

Kontak (in Ryan, 1984) obtained a Rb-Sr errorchron suggesting an age of 1550 ± 55 Ma from granite at Walker Lake. This is similar to ages from the Witchdoctor and Burnt Lake Granites, and is probably disturbed. U-Pb zircon data (Krogh et al., in prep.) are concordant at 1647 ± 2 Ma. Ryan (1984) describes an intrusive contact between granodiorite assigned to this unit and metasedimentary rocks of the Upper Aillik Group in the Walker Lake area. The contact with the syn-tectonic Makkovikian Melody Granite corresponds with an inferred fault zone.

The Otter Lake - Walker Lake Granite is dominated by grey to pink or green-white, medium to coarse grained, porphyritic to seriate quartz monzonite, granodiorite and monzogranite (Table 5.1; Plate 5.7). Melanocratic dioritic variants occur locally. Both K-feldspar and plagioclase phenocrysts are present; in most examples the former are larger, up to 3-5 cm in size. Characteristic features include pale green, saussuritized plagioclase, and blue-grey interstitial quartz, both noted also by Ryan (1984).

Recrystallization is most intense in the south and close to inferred faults; many samples in the north are undeformed and retain good igneous textures. Microcline phenocrysts are finely perthitic and locally have rims of sodic plagioclase. Plagioclase phenocrysts display normal zonation, and contain saussuritized centers. Green or green-brown biotite is the dominant mafic silicate,
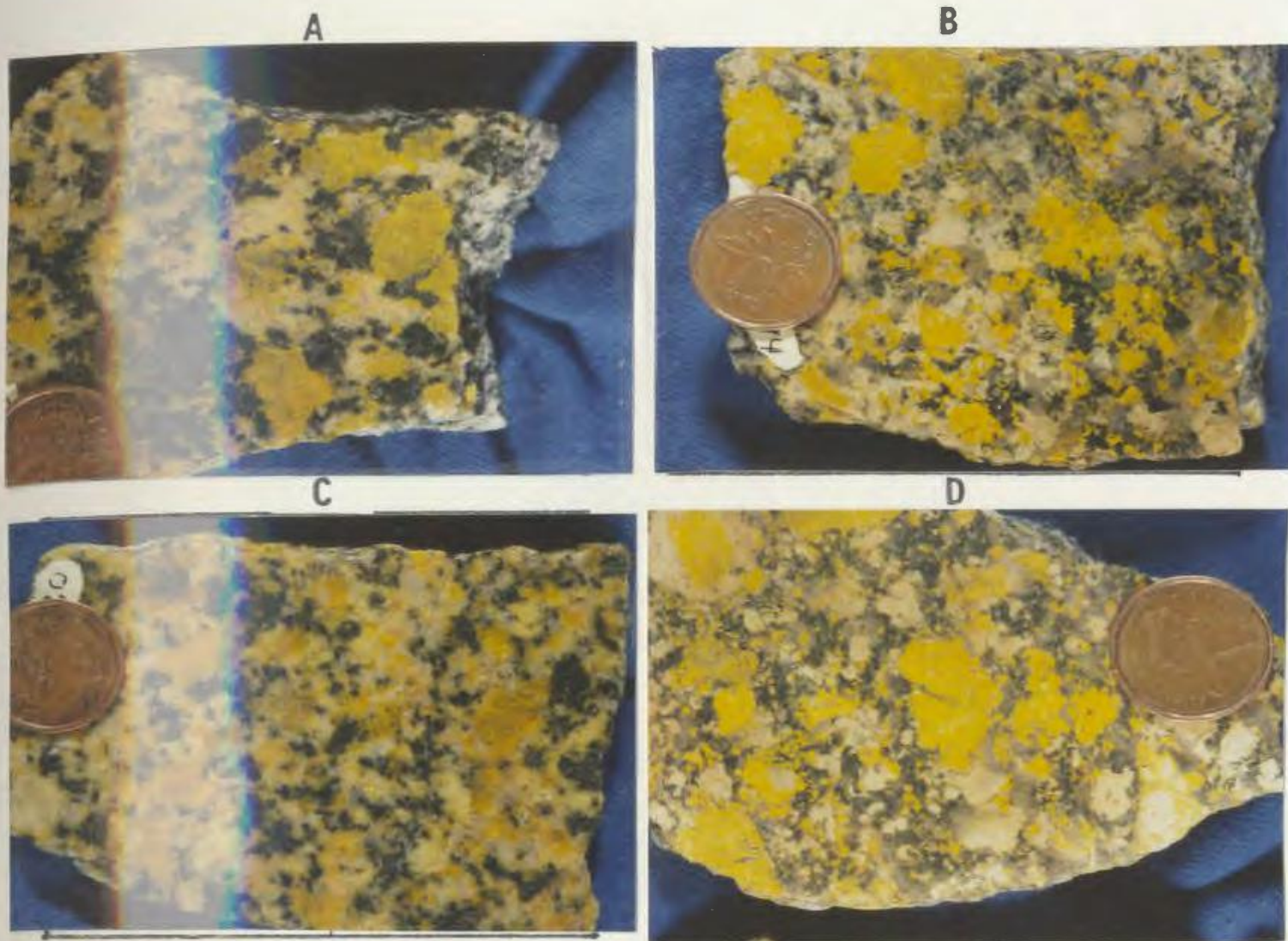
Plate 5.7. Features of the Otter Lake - Walker Lake Granitoid. (a) to (d) Typical quartz monzonite to monzogranite samples, showing variable recrystallization and deformation, but with well-preserved igneous textures. All samples from the Walker Lake area. Slabs stained for K-feldspar.

associated with lesser green hornblende. Relict
clinopyroxene, altered to hornblende, is present rarely.
Sphene is abundant in most samples, and locally occurs in
amounts comparable to hornblende or biotite. It forms
euhedral or subhedral crystals up to 3 mm in size, and in
places displays a clear interstitial habit. Epidote and/or
chlorite are important as alteration products of
plagioclase, and are the dominant mafic silicates in the
most strongly deformed samples.

5.2 DESCRIPTIVE GEOCHEMISTRY

Labradorian plutonic rocks are represented by 429 samples; 247 of these are regional samples collected on a 2 km random grid spacing. The remainder include 99 follow-up samples (from the Monkey Hill, Adlavik and Mount Benedict Intrusive Suites), and 83 geological samples distributed amongst all units.

5.2.1 General Geochemistry

Summary of Numerical Data

Average compositions of principal Labradorian plutonic units are listed in Table 5.2. Four main groupings are apparent.

The Adlavik Intrusive Suite is dominated by SiO_2-poor (< 60%) rocks, and has the highest levels of CaO, MgO, FeO and TiO_2 and compatible OCC trace elements. Geographic divisions of the suite have similar mean compositions, except for the relatively siliceous gabbro at East Micmac Lake.

The Mount Benedict Intrusive Suite is dominated by rocks with 60 to 70% SiO_2. It is strongly enriched in Rb, Cs, U, Th, F and Zr compared to all other Labradorian units; enrichment is generally strongest in the syenite to granite unit. The least differentiated unit is similar in mean composition to diorite of the Adlavik Suite.

The Monkey Hill Intrusive Suite consists of high-silica (72-75% SiO_2) granites that have low levels of CaO, FeO and MgO. However, trace element patterns are relatively

Table 5.2 . Average compositions of Labradorian plutonic units, subdivided by principal units.

UNIT	40.1		40.2		40.3		40.4		41.1		41.2		41.3	
n1	85		17		2		11		12		6		3	
n2	15		1		0		0		2		2		1	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	49.94	4.57	48.03	1.82	55.55	0.35	49.77	3.34	58.21	3.21	56.46	2.79	58.43	1.33
TiO2	0.94	0.44	1.03	0.32	0.60	0.01	1.15	0.46	0.82	0.31	0.86	0.21	0.80	0.12
Al2O3	15.80	3.98	14.81	3.23	16.24	1.49	15.79	2.61	17.86	1.26	18.61	1.08	17.44	0.67
Fe2O3	3.05	1.48	3.65	1.11	1.90	0.00	2.61	0.81	1.93	0.76	2.13	0.40	1.91	0.28
FeO	6.15	1.77	6.82	0.80	5.41	1.03	6.65	1.25	3.85	1.43	4.49	1.46	5.15	0.02
MnO	0.16	0.04	0.18	0.03	0.12	0.03	0.17	0.03	0.13	0.03	0.12	0.03	0.11	0.01
MgO	7.62	5.32	8.42	3.08	5.45	0.76	7.42	5.16	2.26	1.57	2.35	1.13	2.94	0.26
CaO	9.67	3.04	10.45	1.92	7.07	0.59	8.11	2.00	4.60	1.99	5.71	1.57	4.88	0.80
Na2O	3.08	1.20	2.63	0.91	3.67	0.44	3.36	1.12	5.38	1.02	4.35	0.50	3.84	0.03
K2O	1.47	0.92	1.51	0.48	2.05	0.25	2.17	1.07	3.40	0.97	3.39	1.31	3.42	0.26
P2O5	0.34	0.39	0.29	0.17	0.25	0.00	0.41	0.43	0.30	0.15	0.38	0.12	0.31	0.14
LOI	1.38	0.79	1.61	0.56	1.31	0.35	1.45	0.84	0.75	0.31	0.94	0.31	1.19	1.16
TOTAL	99.60		99.43		99.62		99.06		99.49		99.79		100.42	

(ppm)	Trace Elements													
Li	21.7	9.2	21.7	6.4	18.5	2.1	31.0	9.9	20.6	7.8	20.0	4.0	22.3	2.5
F	732.6	1120	873.5	393.0	385.0	62.2	654.4	317.9	804.8	340.9	913.3	353.4	716.7	127.2
Sc	32.3	16.2	32.9						15.0	0.0	16.9	9.8	12.0	
V	203.5	110.6	223.8	68.0	172.0	36.8	183.2	56.2	79.3	67.7	117.0	41.9	97.7	66.7
Cr	275.8	444.3	288.1	276.5	171.5	46.0	338.9	463.7	29.7	34.4	19.2	13.6	23.7	2.1
Ni	78.2	128.4	57.2	41.4	45.5	6.4	98.3	150.9	11.0	12.0	8.3	5.4	15.3	0.6
Cu	50.7	41.0	48.9	23.2	88.5	37.5	50.0	35.1	18.8	14.4	33.0	18.4	18.0	11.3
Zn	96.7	40.1	97.4	22.0	75.5	3.5	100.9	22.7	75.7	19.6	83.8	10.2	71.0	13.2
Ga	20.5	6.1	19.9	3.6	20.5	0.7	18.9	5.2	16.3	5.6	21.7	1.4	17.7	0.6
Rb	41.6	29.9	44.1	18.0	42.5	0.7	56.6	31.5	73.8	23.5	83.5	26.8	91.7	6.7
Sr	760.5	297.8	661.5	382.2	804.0	234.8	677.5	182.0	687.0	225.6	612.3	125.0	615.0	150.7
Y	19.2	10.5	23.2	6.5	11.0	4.2	19.3	9.7	21.3	6.9	33.5	9.3	17.0	1.7
Zr	73.1	64.4	115.4	79.9	87.5	1.0	116.3	87.5	99.3	58.5	351.0	159.1	116.0	12.3
Nb	3.6	4.2	3.9	4.2	2.0	0.0	3.4	2.7	10.2	3.5	13.2	6.6	5.0	0.0
Mo	3.4	1.1	5.7	8.6	3.0	0.0	4.0	2.5	3.1	0.7	4.2	2.1	3.3	0.6
Sn	1.0	0.0	1.0						1.0	0.0	1.5	0.7	1.0	
Cs	1.1	1.7	0.5						1.3	1.1	2.0	0.0	0.5	
Ba	597.9	338.3	504.5	227.8	983.5	79.9	940.1	839.7	1734.6	1297	902.8	209.2	855.0	113.5
La	22.5	14.6	28.8	18.6	30.5	2.1	28.6	15.6	34.8	9.8	47.2	9.5	28.7	5.1
Ce	48.0	30.2	55.7	39.9	55.5	3.5	54.4	32.4	61.1	23.5	96.5	29.6	58.0	8.0
Sm	5.4	2.2	8.1						6.5	0.5	7.1	0.3	5.4	
Yb	2.5	0.0	2.5						2.5	0.0	2.5	0.0	2.5	
Hf	2.3	2.0	1.0						3.0	0.0	3.5	0.7	3.0	
Pb	5.2	7.0	1.9	1.7	8.5	0.7	3.8	3.8	9.4	4.2	10.7	4.3	7.0	5.2
Th	2.2	2.9	1.3	1.3	1.5	0.7	1.7	1.9	3.1	3.8	7.0	4.3	12.3	9.0
U	1.0	0.9	1.1	0.8	0.9	0.1	1.2	1.0	1.8	1.3	3.2	1.3	1.8	0.1

(Wt%)	Partial CIPW Norms													
Q	0.81	2.64	0.00	0.00	2.82	0.80	0.05	0.00	1.60	2.92	2.57	3.67	6.68	
C	0.03	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	
Or	8.80	5.50	9.09	2.90	12.31	1.48	13.06	0.18	20.32	5.84	20.24	7.84	20.34	
Ab	24.81	10.83	20.09	7.20	31.56	3.88	27.11	2.46	45.78	8.57	37.13	4.27	32.71	
An	25.29	9.12	24.67	5.39	22.12	2.98	22.08	0.25	14.73	5.61	21.48	6.27	18.85	
Ne	0.89	1.35	1.42	1.84	0.00	0.00	1.08	0.00	0.14	0.35	0.02	0.05	0.00	
Di	17.21	12.49	21.39	10.65	9.98	4.68	13.48	0.86	5.51	4.30	4.17	2.82	3.19	
Hy	5.20	6.01	4.15	6.40	16.63	1.49	2.59	0.47	5.10	4.25	7.27	4.79	12.60	
Ol	9.70	10.15	11.02	3.55	0.00	0.00	13.38	2.26	1.69	2.73	1.42	2.69	0.00	
Mt	4.50	2.21	5.40	1.65	2.80	0.01	3.87	0.13	2.83	1.11	3.12	0.58	2.79	
Il	1.82	0.86	2.00	0.63	1.15	0.02	2.23	0.03	1.57	0.61	1.66	0.39	1.53	

KEY TO UNITS (AIS - Adlavik Intrusive Suite)
40.1 (AIS) Gabbro-Gabbronorite (Type Area)   41.1 (AIS) Diorite (Type Area)
40.2 (AIS) Gabbro-Gabbronorite (Southern Area)   41.2 (AIS) Diorite (Southern Area)
40.3 (AIS) Gabbro-Gabbronorite (East Nicmac)   41.3 (AIS) Diorite (East Nicmac)
40.4 (AIS) Gabbro-Gabbronorite (Eastern Area)

n1 -- Number of analyses for all elements except those listed below.
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf.

Table 5.2 (continued).

UNIT	42.0		43.0		44.0		46.0		47.0		48.0	
n1	17		53		67		17		17		49	
n2	1		22		39		12		17		11	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO_2	55.52	3.22	64.46	4.46	70.69	3.31	73.78	3.33	72.71	3.11	68.54	4.42
TiO_2	0.97	0.20	0.61	0.24	0.30	0.18	0.15	0.15	0.16	0.07	0.44	0.20
Al_2O_3	18.23	1.64	16.03	0.93	14.39	1.06	13.77	1.22	14.18	1.74	14.98	1.62
Fe_2O_3	1.99	0.49	1.40	0.66	0.97	0.40	0.65	0.59	0.57	0.25	1.20	0.61
FeO	4.43	1.16	2.53	1.12	1.09	0.66	0.63	0.26	0.60	0.36	1.87	1.01
MnO	0.13	0.03	0.09	0.03	0.05	0.02	0.04	0.01	0.03	0.01	0.06	0.03
MgO	2.79	1.89	1.12	0.97	0.38	0.27	0.15	0.12	0.21	0.14	0.86	0.54
CaO	5.52	1.54	2.37	1.52	0.97	0.49	0.75	0.41	0.80	0.30	2.04	1.02
Na_2O	4.37	0.44	4.51	0.36	4.28	0.43	4.13	0.40	4.40	1.53	3.89	0.55
K_2O	3.61	0.95	5.41	0.93	5.58	0.51	5.04	0.64	4.93	1.07	4.70	0.62
P_2O_5	0.42	0.24	0.19	0.17	0.05	0.06	0.02	0.03	0.03	0.02	0.15	0.09
LOI	1.26	0.56	0.84	0.23	0.75	0.11	0.45	0.14	0.54	0.10	0.77	0.24
TOTAL	99.24		99.56		99.50		99.56		99.16		99.50	
(ppm)												
Li	32.7	12.4	31.0	10.4	25.3	11.0	14.3	13.6	27.2	23.1	25.7	12.5
F	975.1	365.5	1298.0	410.7	1240.5	617.4	137.9	97.7	217.5	130.7	679.1	257.1
Sc	6.7		5.8	2.1	2.9	1.7	2.3	1.4	1.6	1.0	6.8	2.4
V	107.9	39.5	50.6	40.9	23.1	13.1	13.1	5.7	16.3	7.7	44.6	30.2
Cr	42.3	81.7	14.5	16.6	6.5	3.8	3.8	4.9	3.2	2.3	6.5	7.0
Ni	20.7	43.2	4.3	5.3	1.9	1.7	1.8	2.3	1.5	1.9	2.1	3.0
Cu	56.9	40.0	18.9	16.9	10.1	8.8	3.4	2.6	4.2	4.6	9.1	18.7
Zn	92.1	25.5	60.3	19.1	39.9	14.0	25.1	8.2	32.5	12.1	46.9	21.4
Ga	19.4	4.5	11.3	4.7	8.6	2.1	11.5	7.1	11.9	4.1	12.8	4.1
Rb	130.0	46.4	233.2	81.8	315.3	81.3	169.5	49.6	212.8	78.4	140.5	38.7
Sr	766.5	216.7	308.9	191.0	126.8	108.3	75.4	83.5	98.8	67.7	277.7	154.8
Y	24.7	6.8	30.3	8.7	27.8	7.6	23.7	27.5	27.1	6.2	28.2	10.2
Zr	236.0	190.9	408.0	190.7	345.0	140.0	198.5	232.5	172.7	82.7	240.0	83.8
Nb	10.7	5.0	21.2	8.1	29.0	8.6	16.9	16.4	25.1	8.0	13.6	4.4
Mo	4.7	3.5	4.7	1.5	4.3	2.7	3.4	0.9	52.8	202.1	3.2	1.2
Sn	14.0		6.1	4.2	7.2	4.2	1.8	1.1	2.8	2.5	3.9	3.3
Cs	6.4		10.7	5.3	9.0	4.3	1.8	1.2	2.0	1.4	4.1	1.8
Ba	1115.7	409.1	742.8	360.6	381.9	352.6	515.1	912.7	522.9	328.7	961.5	542.3
La	44.0	10.5	50.7	13.1	56.3	22.9	28.0	25.9	34.3	17.6	50.6	14.8
Ce	89.9	22.5	108.3	30.3	114.0	43.7	60.9	55.4	65.9	33.2	100.1	28.5
Sm	10.1		8.2	1.7	6.9	1.7	3.9	1.4	4.4	2.2	9.3	3.0
Yb	4.5		4.1	1.0	4.5	0.9	2.5	0.0	3.0	0.7	2.5	0.0
Hf	20.0		12.2	3.0	9.9	3.1	5.0	1.0	6.0	1.6	12.5	21.1
Pb	12.5	4.6	17.8	6.1	23.4	8.0	22.2	5.8	31.4	14.0	16.8	8.1
Th	7.8	5.5	21.6	13.6	37.5	13.8	18.0	7.7	20.3	10.8	14.8	7.3
U	3.3	1.7	6.8	3.2	10.4	4.4	5.6	4.0	9.3	5.2	4.0	2.4
(Wt%)												
Q	1.10	1.85	10.94	6.32	22.13	7.27	27.10	9.76	26.52	9.82	22.14	8.29
C	0.00	0.00	0.02	0.10	0.12	0.24	0.25	0.20	0.26	0.23	0.26	0.36
Or	21.71	5.63	32.33	5.51	33.36	3.06	30.05	3.80	29.51	6.44	28.14	3.71
Ab	37.43	3.77	38.63	3.09	36.65	3.68	35.25	3.46	37.53	12.63	33.29	4.70
An	19.86	5.90	7.58	4.35	3.30	1.78	3.49	1.66	3.73	1.66	8.95	4.23
Ne	0.13	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.47	0.00	0.00
Di	4.71	2.44	2.60	2.33	0.79	0.82	0.14	0.41	0.18	0.42	0.49	0.74
Hy	7.01	4.62	3.90	2.08	1.41	1.11	0.82	0.56	0.92	0.69	3.77	2.10
Ol	2.18	3.19	0.25	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mt	2.95	0.73	2.03	0.96	1.36	0.59	0.85	0.54	0.79	0.38	1.76	0.90
Il	1.89	0.39	1.17	0.47	0.58	0.34	0.28	0.28	0.31	0.14	0.85	0.38

KEY TO UNITS (MBIS - Mount Benedict Intrusive Suite)
42 (MBIS) Gabbro to Monzodiorite
43 (MBIS) Monzonite, Syenomonzonite, Syenite
44 (MBIS) Syenite, Quartz Syenite, Granite

46.0 -- Witchdoctor Granite
47.0 -- Burnt Lake Granite
48.0 -- Otter Lake - Walker Lake Granitoid

n1 -- Number of analyses for all elements except those listed below.
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf.

Table 5.2 (continued).

UNIT	45.1		45.2		45.3		45.4		45.5		45.6	
n1	33		4		8		13		3		6	
n2	29		2		6		10		3		5	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	72.97	5.86	75.69	1.69	72.49	2.89	74.62	2.44	72.77	3.16	74.05	0.68
TiO2	0.14	0.14	0.04	0.01	0.14	0.12	0.12	0.07	0.18	0.09	0.18	0.04
Al2O3	13.39	1.48	12.75	0.21	13.82	1.11	13.47	0.84	14.38	0.94	13.59	0.13
Fe2O3	1.57	4.65	0.42	0.07	0.78	0.78	0.55	0.23	0.59	0.62	0.66	0.28
FeO	0.88	2.23	0.12	0.08	0.58	0.47	0.49	0.52	0.90	0.40	0.84	0 23
MnO	0.06	0.04	0.01	0.00	0.04	0.02	0.04	0.02	0.04	0.03	0.04	0.01
MgO	0.21	0.22	0.06	0.02	0.15	0.13	0.26	0.37	0.26	0.20	0.35	0.28
CaO	0.75	0.54	0.38	0.10	0.84	0.29	0.80	0.36	1.01	0.42	0.86	0.16
Na2O	4.23	0.85	4.34	0.28	4.78	2.50	4.24	0.25	4.13	0.25	3.84	0.65
K2O	4.69	1.23	4.33	0.44	4.59	1.89	4.58	0.37	4.99	0.27	4.98	1.18
P2O5	0.03	0.04	0.01	0.00	0.04	0.03	0.03	0.04	0.06	0.04	0.04	0.01
LOI	0.63	0.20	0.50	0.11	0.72	0.44	0.54	0.33	0.47	0.19	0.43	0.13
TOTAL	99.55		98.65		98.97		99.74		99.78		99.86	
(ppm)												
Li	24.1	14.6	5.5	1.0	13.1	5.4	15.0	5.6	16.7	3.5	32.8	15.8
F	685.2	463.3	258.3	201.4	199.4	194.1	369.5	295.0	119.3	109.6	780.2	502.0
Sc	1.3	0.8	0.3	0.0	1.9	1.2	0.7	0.3	1.6	0.9	2.5	0.9
V	17.7	24.9	12.0	5.3	20.1	7.1	14.8	11.1	22.0	7.2	19.3	8.2
Cr	3.7	2.4	2.0	0.8	1.8	1.0	7.9	13.6	1.0	0.0	3.7	4.4
Ni	1.2	0.7	1.0	0.0	1.0	0.0	2.3	2.8	1.0	0.0	1.0	0.0
Cu	11.1	25.2	11.8	7.4	15.9	28.7	5.4	6.7	3.3	2.3	3.0	3.2
Zn	42.5	40.3	9.0	3.2	24.3	13.0	29.5	13.9	35.7	4.7	40.5	12.5
Ga	12.8	8.6	11.3	2.6	11.3	4.7	9.7	3.3	13.7	1.2	13.0	4.7
Rb	201.1	77.7	184.8	38.9	119.5	51.2	160.1	31.7	102.0	11.5	229.3	44.1
Sr	156.2	294.4	29.0	16.8	130.1	101.9	145.6	79.7	176.7	110.0	95.2	20.1
Y	34.5	30.1	11.5	1.3	20.3	11.9	20.5	7.4	12.0	2.7	25.0	7.4
Zr	178.1	111.4	100.3	31.9	155.3	80.7	116.0	53.8	123.3	14.5	219.0	48.1
Nb	19.6	10.4	17.0	9.7	13.3	2.7	15.1	4.6	8.7	3.8	20.7	2.2
Mo	146.1	826.9	2.3	1.0	129.1	356.7	1.9	0.5	2.3	0.6	1.8	1.0
Sn	3.0	2.2	1.0	0.0	1.8	1.6	2.4	2.1	1.0	0.0	5.4	2.6
Cs	3.0	2.5	0.5	0.0	1.0	0.8	1.6	1.3	0.5	0.0	2.4	1.2
Ba	343.9	263.8	47.0	21.4	589.0	339.6	292.6	387.7	892.0	549.1	424.8	160.8
La	22.8	21.5	3.8	3.5	24.9	22.9	16.2	9.5	14.7	10.3	37.3	22.2
Ce	49.8	47.7	4.0	4.8	46.1	38.6	30.9	18.5	79.3	13.6	79.0	37.2
Sm	5.1	4.9	1.0	0.4	5.1	2.7	2.5	0.9	2.7	0.6	5.3	2.2
Yb	5.0	4.7	2.5	0.0	3.3	1.8	2.6	0.2	2.5	0.0	2.9	0.6
Hf	6.0	3.2	3.0	0.0	5.5	2.7	4.0	0.8	4.0	1.0	8.3	2.8
Pb	23.5	9.6	13.0	5.4	19.4	8.3	22.6	7.5	15.7	6.4	29.8	11.2
Th	14.5	9.2	7.0	2.9	13.3	8.2	13.2	7.5	3.3	4.0	20.2	3.9
U	6.8	6.4	5.0	2.7	4.2	2.2	4.5	2.2	2.3	1.1	9.6	4.7
(Wt%)												
Q	28.74	5.32	33.60	1.86	25.39	9.02	30.50	4.64	26.87	4.34	30.17	8.78
C	0.23	0.24	0.27	0.23	0.22	0.25	0.23	0.25	0.40	0.35	0.37	0.17
Or	27.62	7.13	26.04	2.64	26.01	11.37	27.27	2.19	29.69	1.47	29.56	16.89
Ab	36.50	7.10	37.45	2.64	42.22	19.80	36.13	2.16	35.18	2.32	32.66	14.46
An	3.14	1.77	1.85	0.49	2.82	1.72	3.62	1.43	4.91	2.00	4.17	1.73
Ne	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di	0.26	0.66	0.00	0.00	0.65	1.69	0.19	0.34	0.00	0.00	0.01	0.66
Hy	0.75	0.87	0.16	0.06	0.81	0.77	0.96	1.45	1.60	0.87	1.64	0.40
Ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mt	2.09	7.19	0.30	0.25	0.35	0.39	0.66	0.40	0.87	0.91	0.97	0.12
Il	0.27	0.27	0.08	0.01	0.28	0.24	0.23	0.14	0.34	0.17	0.34	0.20

KEY TO UNITS (MHIS - Monkey Hill Intrusive Suite)
45.1 (MHIS) Monkey Hill Granite   45.5 (MHIS) Bent's Cove Granite
45.2 (MHIS) Round Pond Granite   45.6 (MHIS) Kidlaluit Granite
45.3 (MHIS) Duck Island Granite
45.4 (MHIS) Little Monkey Hill Granite

n1 -- Number of analyses for all elements except those listed below.
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf.

unevolved; Rb, Cs, U and Th abundances are moderate and F, Zr, La and Ce are depleted relative to most other units. Note that high mean Mo values for some plutons reflect mineralized samples, and are not typical of the units as a whole. Individual plutons are otherwise similar, except for the Round Pond Granite, which shows strong depletion of Zn, Sr, Y, Zr, Ba, La, Ce, Pb and Th. The Witchdoctor and Burnt Lake Granites are similar in composition to granites of the Monkey Hill Suite.

The Otter Lake - Walker Lake unit has unremarkable major and trace element characteristics, and shows no striking enrichment or depletion patterns.

Abundance and Distribution of Rock Types

IUGS rock types were calculated from normative data after Streckeisen and LeMaitre (1979). Labradorian plutonic rocks include a higher proportion of low-SiO_2 rock types than the Makkovikian assemblage, and are obviously bimodal (Figure 5.5). The Adlavik Intrusive Suite is dominated by gabbro, with lesser diorite to monzonite. The Mount Benedict Intrusive Suite overlaps this range, but is dominated by quartz monzonite to quartz syenite. The Monkey Hill Intrusive Suite and Witchdoctor - Burnt Lake Granites are dominated by granite and alkali-feldspar granite. The Otter Lake - Walker Lake granite is dominated by monzogranite and granite. Mafic or intermediate rock types are essentially absent from the latter three associations, termed "siliceous granitoid units" in subsequent discussions.
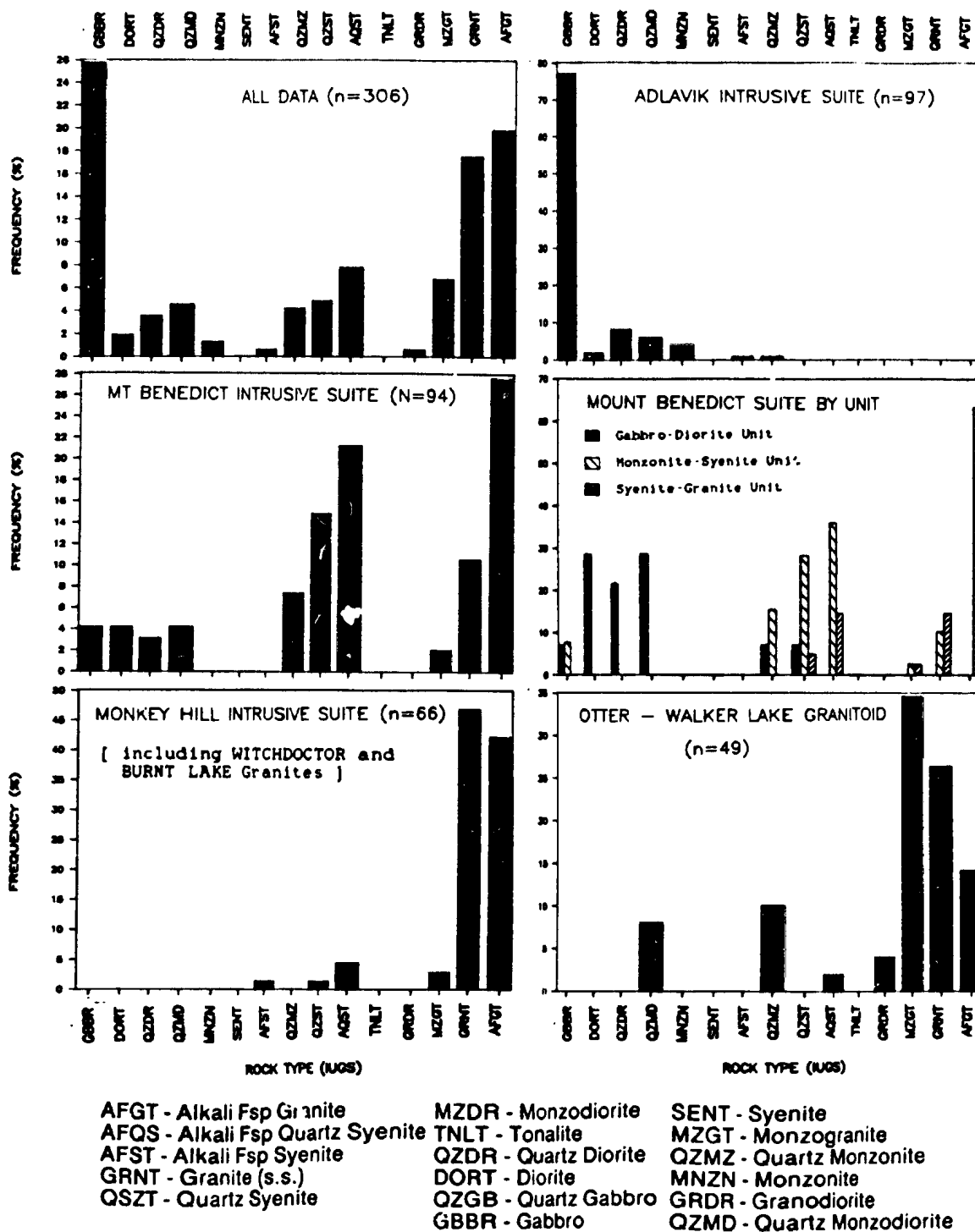
Figure 5.5. Relative abundance of IUGS rock types calculated from
normative mineralogy using the method of Streckeisen and LeMaitre
(1979). Note that this is based on Barth mesonorms, not the CIPW
norms listed in Table 5.2. Regional and geological sample
populations.

5.2.2 Geochemistry of The Adlavik Intrusive Suite

This discussion is based mostly on geochemical data from the main body at Adlavik Bay. Average compositions of textural and mineralogical facies from this area are listed in Table 5.3; the criteria used for subdivision are outlined below.

Subdivisions of The Suite

In addition to subdivision by facies, as outlined in 5.1.1, Table 5.3 incorporates a second-order grouping based on the relative abundance of normative diopside (Di), hypersthene (Hy) and olivine (Ol).

Rocks with well-preserved anhydrous mineral assemblages include both gabbronorite and gabbro variants, which appear to be discrete spatially. However, the widespread late magmatic and/or secondary hydrous mineral assemblages make it difficult to assess primary mineralogy in all areas via petrography.

A Di-Ol-Hy ternary projection (Figure 5.6) illustrates contrasting Hy-normative and Hy-free groups. Both contain variable normative Ol, but most of the Ol-free rocks are also Hy-normative. The diorite unit is also dominantly Hy-normative.

Examination of fresh samples suggests that there is good correspondence between normative and modal hypersthene; the CIPW norms therefore provide a method of classifying altered and hydrated samples, and those for which no petrographic data are available.

The distribution of Hy-normative and Hy-free variants is geographically systematic (Figure 5.7). The leucogabbro facies is predominantly Hy-free, whereas the melagabbro

Table 5.3 . Average compositions of textural and mineralogical
subdivisions in the main body of the Adlavik Intrusive Suite.

KEY	1.0		2.1		2.2		2.3		3.1		3.2	
n1	7		7		2		2		4		7	
n2	1		2		0		1		0		1	
(wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	45.07	2.62	46.39	4.29	53.35	1.48	52.08	0.46	48.78	4.19	50.24	2.18
TiO2	0.86	0.56	0.88	0.50	1.00	0.26	0.82	0.08	0.73	0.19	1.04	0.18
Al2O3	10.46	3.01	13.97	1.64	16.08	1.91	14.64	3.43	21.23	4.34	19.69	1.51
Fe2O3	4.08	1.82	4.41	3.07	3.06	0.15	2.36	0.43	3.12	1.44	3.79	0.78
FeO	6.92	1.30	6.57	2.41	5.87	1.82	7.46	1.20	4.30	1.99	5.13	0.98
MnO	0.17	0.01	0.17	0.02	0.19	0.06	0.19	0.01	0.11	0.04	0.13	0.03
MgO	17.03	8.09	8.91	1.35	5.13	1.45	8.24	4.18	4.05	2.40	3.68	1.08
CaO	8.93	2.56	13.96	2.01	7.31	0.18	7.36	0.30	10.36	2.60	9.00	1.00
Na2O	1.88	0.71	1.89	0.94	3.58	0.77	3.32	1.23	3.49	1.26	3.68	0.24
K2O	1.35	0.51	0.77	0.69	2.07	0.33	1.92	0.47	1.74	1.09	1.28	0.54
P2O5	0.49	0.79	0.09	0.10	0.39	0.25	0.22	0.04	0.37	0.27	0.80	0.46
LOI	2.62	1.64	1.49	0.45	1.56	0.37	1.06	0.98	2.01	0.80	1.13	0.62
TOTAL	99.86		99.50		99.59		99.67		100.29		99.59	

(ppm) Trace Elements

	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Li	26.9	11.6	20.7	4.7	25.5	2.1	20.0	4.2	33.5	23.6	20.4	3.7
F	638.3	324.5	305.9	325.4	804.0	189.5	765.5	27.6	600.5	484.5	1881.4	3570
Sc	25.7		48.8	0.8			23.0				19.0	
V	232.7	158.7	323.9	243.4	216.0	33.9	167.0	15.6	213.5	190.9	201.7	64.4
Cr	1014.0	665.7	140.1	193.7	96.5	123.7	113.0	62.2	78.3	127.9	24.3	19.7
Ni	348.4	277.7	45.1	27.6	26.5	29.0	55.0	19.8	19.0	17.5	13.3	11.2
Cu	52.9	39.2	88.6	49.6	63.5	30.4	28.5	2.1	37.0	29.4	26.4	9.9
Zn	94.6	32.3	100.6	40.7	132.0	41.0	168.5	94.1	71.3	29.9	98.3	16.0
Ga	19.0	8.2	21.6	10.6	19.5	0.7	18.0	7.1	21.3	2.2	25.1	3.3
Rb	41.6	49.9	18.6	7.9	71.0	19.8	61.5	16.3	64.0	45.0	28.4	15.1
Sr	495.6	231.2	730.4	114.9	682.5	202.9	516.0	63.6	1030.5	122.1	981.4	93.0
Y	13.4	11.1	15.3	4.3	25.0	9.9	24.0	2.8	13.3	5.3	20.6	6.4
Zr	38.6	7.7	39.6	20.2	116.0	32.5	104.0	15.6	53.0	52.0	65.4	43.0
Nb	2.9	2.0	1.4	1.7	3.5	0.7	1.0	1.4	5.3	6.7	2.3	2.9
Mo	2.9	0.9	3.9	2.8	3.5	0.7	3.5	0.7	3.8	0.5	3.6	0.5
Sn	1.0		1.0	0.0			1.0				1.0	
Cs	7.0		0.5	0.0			0.9				0.5	
Ba	419.7	98.8	281.7	144.6	831.0	267.3	578.5	161.9	594.8	293.8	647.9	195.6
La	18.4	17.3	8.6	7.5	30.5	10.6	26.5	6.4	22.8	14.4	25.9	9.4
Ce	42.0	45.2	30.7	11.9	58.5	10.6	46.5	7.8	45.8	33.4	57.4	21.5
Sm	3.5		4.4	0.4			5.0				5.6	
Yb	2.5		2.5	0.0			2.5				2.5	
Hf	1.0		1.0	0.0			3.1				3.0	
Pb	2.0	1.7	1.7	1.3	18.5	17.7	11.0	11.3	3.5	3.1	4.1	3.3
Th	2.6	1.5	1.4	1.1	1.0	0.0	1.0	0.0	5.4	4.8	4.2	3.1
U	0.6	0.3	0.5	0.4	2.7	0.9	0.8	0.3	1.3	1.7	0.8	0.4

(Wt%) Partial CIPW Norm

	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Q	0.00	0.00	0.00	0.00	1.81	1.12	0.00	0.00	0.00	0.00	0.98	1.26
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.25	0.24	0.64
Or	8.20	3.08	4.65	4.13	12.47	1.92	11.46	2.74	10.44	6.47	7.67	3.32
Ab	13.59	6.00	13.63	7.09	30.82	6.55	28.52	10.80	25.36	9.60	31.54	2.03
An	16.46	6.43	27.88	7.79	22.13	0.74	19.66	5.48	37.45	15.96	33.25	5.69
Ne	1.47	2.01	1.44	1.64	0.00	0.00	0.00	0.00	2.53	1.41	0.00	0.00
Di	20.47	6.65	33.88	6.95	10.26	0.13	13.14	2.66	10.14	11.34	5.00	3.24
Hy	1.89	2.57	0.17	0.33	15.11	6.60	12.09	11.56	0.00	0.00	11.15	3.38
Ol	28.75	15.59	9.83	4.15	0.00	0.00	9.55	0.08	6.98	2.37	0.45	1.09
Mt	6.08	2.73	6.52	4.56	4.51	0.23	3.46	0.67	4.55	2.12	5.58	1.14
Il	1.67	1.07	1.70	0.98	1.93	0.51	1.58	0.18	1.40	0.37	2.00	0.35

KEY TO ANALYSES
1.0 -- Ultramafic Rocks
2.1 -- Mafic Cumulate Facies (Cpx +/- Ol)
2.2 -- Mafic Cumulate Facies (Cpx + Opx)
2.3 -- Mafic Cumulate Facies (Cpx + Opx + Ol)

3.1 -- Melanocratic Gabbro Facies (Cpx +/- Ol)
3.2 -- Melanocratic Gabbro Facies (Cpx + Opx)

n1 -- Number of analyses for all elements except those below
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf

Table 5.3 (continued)

KEY	4.1		4.2		4.3		5.0		7.0	
n1	26		8		10		14		7	
n2	5		0		2		2		1	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	47.64	2.86	54.07	2.17	51.49	1.69	57.90	3.01	53.42	5.46
TiO2	1.01	0.55	0.86	0.20	0.81	0.18	0.81	0.30	1.16	0.72
Al2O3	14.59	3.93	18.88	2.76	16.36	3.89	17.85	1.28	15.07	2.46
Fe2O3	2.88	1.35	2.41	0.75	2.38	0.56	1.94	0.72	2.98	1.42
FeO	6.98	1.56	4.88	1.47	6.09	0.81	4.01	1.45	6.04	2.14
MnO	0.18	0.04	0.13	0.04	0.15	0.04	0.13	0.03	0.17	0.03
MgO	9.22	4.68	3.62	1.46	7.45	4.94	2.46	1.55	6.07	3.54
CaO	11.57	2.80	7.50	1.48	8.82	1.30	4.83	1.92	7.31	2.60
Na2O	2.59	1.29	4.20	0.46	3.40	1.09	5.27	1.02	3.60	1.07
K2O	0.99	0.70	1.86	0.62	1.44	0.57	3.31	0.93	2.28	0.86
P2O5	0.30	0.37	0.27	0.08	0.17	0.10	0.31	0.15	0.41	0.40
LOI	1.49	0.51	0.77	0.39	0.97	0.36	0.77	0.34	1.21	0.39
TOTAL	99.44		99.45		99.53		99.59		99.72	
(ppm)										
Li	17.8	7.3	20.4	5.5	20.3	4.8	19.2	7.0	26.0	8.1
F	516.2	404.1	547.8	196.6	583.7	452.0	840.2	394.4	1286.0	896.0
Sc	43.0	19.0			21.9	6.9	15.0	0.0	20.0	
V	202.6	82.3	156.3	57.0	185.6	35.0	91.8	68.0	171.0	60.4
Cr	345.2	440.8	47.3	36.5	365.8	563.4	29.4	33.1	234.9	253.8
Ni	83.3	85.2	16.8	9.1	88.1	104.5	10.9	11.3	58.1	44.3
Cu	72.3	49.1	22.8	15.9	41.2	28.6	23.0	16.2	33.0	24.0
Zn	87.9	44.6	88.0	22.6	88.6	20.8	77.4	18.8	129.1	51.2
Ga	18.5	6.1	22.4	2.7	20.2	3.1	16.6	5.1	22.3	6.1
Rb	28.0	22.1	49.1	19.1	41.4	19.9	75.8	23.2	64.1	29.1
Sr	774.6	381.5	927.5	202.3	798.1	295.3	711.8	202.7	610.1	243.3
Y	17.8	10.3	18.1	4.6	16.8	5.5	20.7	4.6	37.3	17.2
Zr	52.3	43.0	83.4	39.4	69.4	47.0	95.9	50.6	179.0	102.8
Nb	2.3	3.1	5.1	2.9	3.7	3.1	10.0	3.4	8.9	6.4
Mo	3.0	0.5	3.8	0.5	3.6	1.7	2.9	0.8	3.6	0.8
Sn	1.0	0.0			1.0	0.0	1.0	0.0	1.0	
Cs	0.5	0.0			0.5	0.0	1.3	1.1	2.0	
Ba	542.2	455.0	776.4	215.4	593.4	276.9	1554.1	1251	824.0	483.5
La	17.5	13.9	27.5	7.0	20.8	11.0	33.4	8.2	38.3	16.5
Ce	40.3	31.3	51.1	14.1	39.3	18.8	58.6	20.7	81.6	34.9
Sm	4.5	2.5			7.0	1.5	6.5	0.5	6.2	
Yb	2.5	0.0			2.5	0.0	2.5	0.0	2.5	
Hf	1.5	0.9			2.0	1.4	3.0	0.0	5.0	
Pb	2.5	3.4	5.8	3.5	9.3	14.0	9.7	4.6	8.9	5.7
Th	1.3	0.9	1.7	2.6	0.8	0.3	3.0	3.3	5.2	4.5
U	0.5	0.5	1.5	1.0	0.9	0.6	2.0	1.3	1.9	1.1
(Wt%)										
Q	0.36	1.83	1.13	1.07	0.00	0.00	1.31	1.64	2.19	4.02
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	5.94	4.23	11.09	3.72	8.62	3.45	19.79	5.61	13.63	5.06
Ab	19.29	10.55	35.94	3.99	29.08	9.30	44.86	8.61	30.82	9.13
An	25.76	7.97	27.56	8.91	25.46	6.67	15.42	5.94	18.51	5.92
Ne	1.65	1.29	0.00	0.00	0.00	0.00	0.12	0.33	0.00	0.00
Di	24.95	13.43	7.05	3.78	14.57	8.25	5.84	4.05	12.59	10.01
Hy	0.40	2.01	10.84	4.18	8.07	3.07	6.06	4.82	9.64	4.21
Ol	14.59	7.34	0.49	1.34	8.64	6.09	1.45	2.58	4.90	4.63
Mt	4.26	2.02	3.54	1.10	3.49	0.82	2.85	1.06	4.39	2.12
Il	1.97	1.07	1.65	0.38	1.56	0.34	1.55	0.58	2.23	1.41

KEY TO ANALYSES
4.1 -- Plagioclase Cumulate Facies (Cpx +/- Ol)
4.2 -- Plagioclase Cumulate Facies (Cpx + Opx)
4.3 -- Plagioclase Cumulate Facies (Cpx + Opx + Ol)

5.0 -- Diorite Unit (mostly Cpx + Opx)
7.0 -- Marginal Gabbro and Diorite

n1 -- Number of analyses for all elements except those below
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf
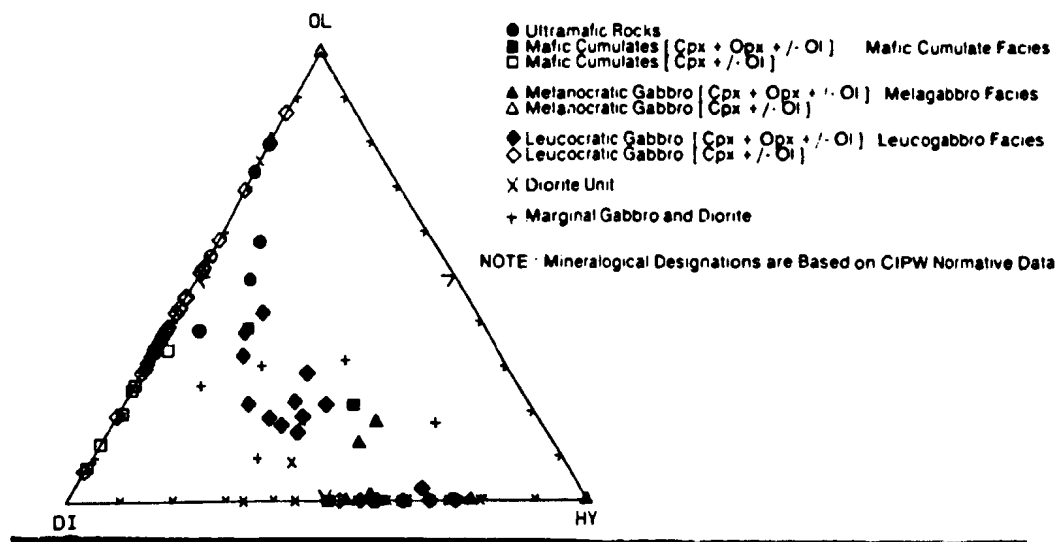
Figure 5.6. Normative olivine - diopside - hypersthene projection, showing the division of the Adlavik Intrusive Suite into hypersthene-normative and hypersthene-free components.

facies is Hy-normative. The mafic cumulate facies contains both types. As expected, there are major element geochemical contrasts between Hy-normative and Hy-free rocks, and also some trace element differences (Table 5.3).

It is suggested on this basis that the intrusion be divided into gabbronorite and gabbro sequences. The former includes the mafic cumulate facies, melagabbro facies and part of the leucogabbro facies, and is probably associated with the Hy-normative diorite unit. The gabbro sequence includes most of the leucogabbro facies, and is considered to represent stratigraphically higher parts of the complex (see cross section, Figure 5.4). The gabbronorite sequence includes Hy-free mafic cumulate rocks, but the gabbro sequence is only rarely Hy-normative.
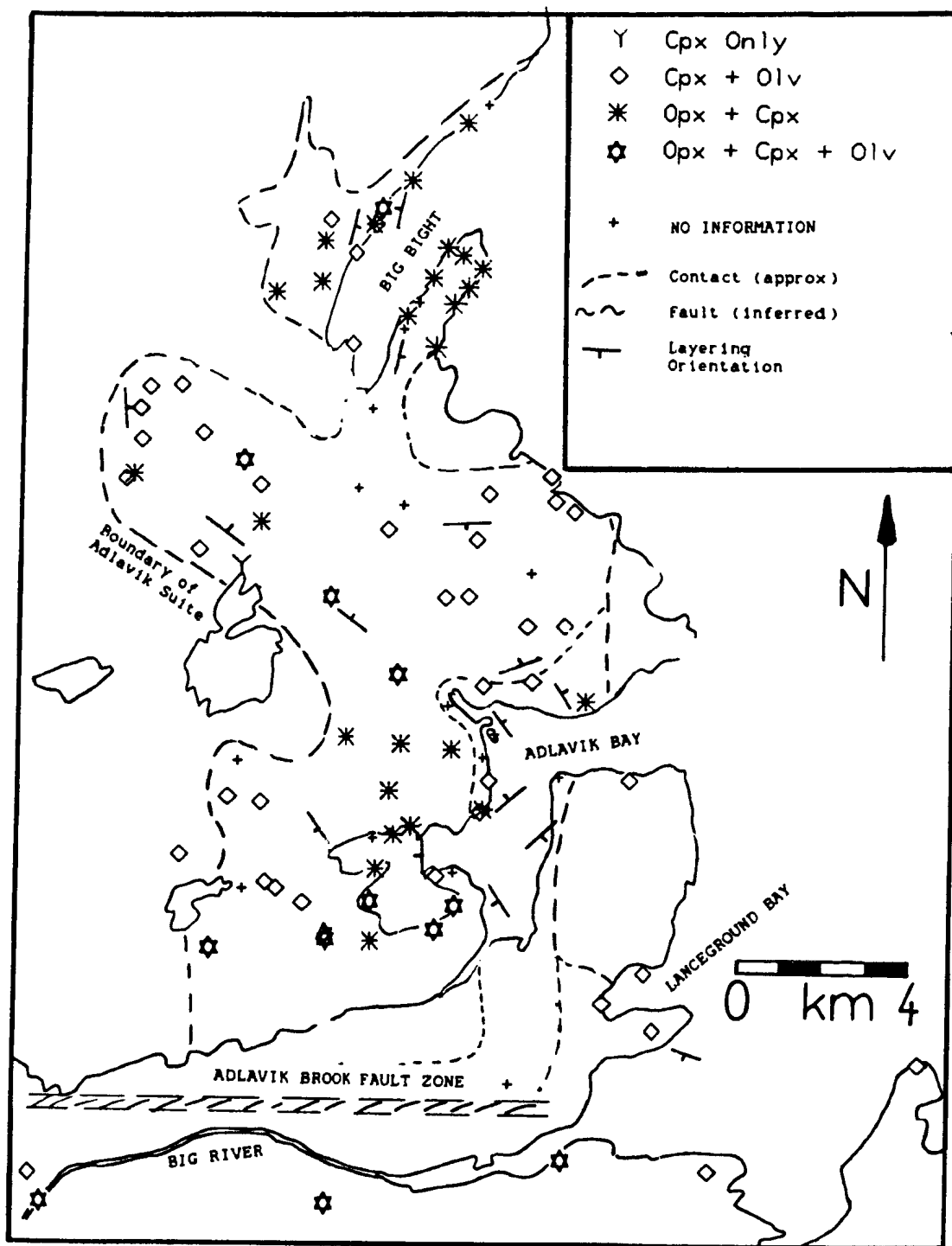
Figure 5.7. Spatial variation of normative mineralogy in the main body of the Adlavik Intrusive Suite, illustrating distribution of gabbronorite and gabbro sequences.

Major Element Patterns

Major element variation is assessed using MgO as a differentiation index (Figure 5.8). The clearest distinction between gabbronorite and gabbro sequences is shown by TiO_2, which is strongly enriched in the latter below 10% MgO. The gabbronorite sequence has convex-upward CaO and FeO trends, and lower CaO and FeOt than the gabbro sequence above 10% MgO. It also shows higher SiO_2 and K_2O (see also Table 5.3), but there is considerable overlap between the two. Samples from fine-grained marginal rocks have varied compositions, and clearly do not represent any one homogeneous "parental" composition.

Trace Element Patterns

Trace elements show predictable trends for mafic magmas (Figure 5.9), and there are few systematic differences between gabbronorite and gabbro sequences.

Compatible OCC trace elements (e.g. Cr, V, Cu; Figure 5.9) are positively correlated with MgO. High Cu contents characterize parts of the gabbro sequence. V shows minimal variation from 30% to 5 % MgO, and possibly increases slightly down to this point. It is, however, depleted very rapidly below 5% MgO, and in the diorite unit.

LFS and HFS elements, and REE, increase with decreasing MgO, and, except for Sr, are highest in the diorite unit. Sr enrichment is most apparent in the gabbro sequence, reflecting the presence of plagioclase cumulates. The dioritic unit shows lower Sr than either the gabbronorite or gabbro sequence, but is closer to the former. Ba is incompatible throughout, and is strongly enriched in some samples from the diorite unit, which
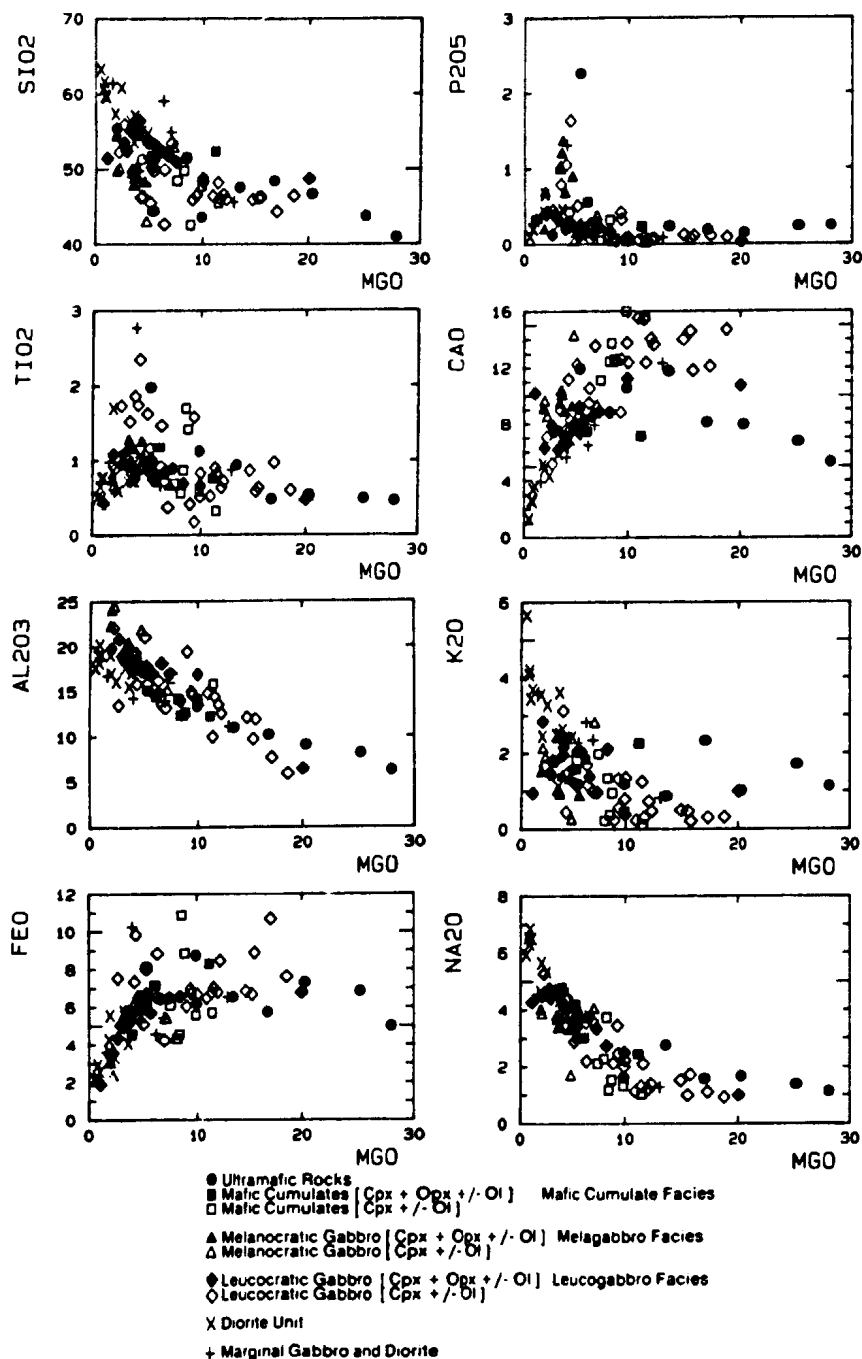
Figure 5.8. Variation of selected major elements and derived ratios against MgO in the main body of the Adlavik Intrusive Suite. See text for discussion.
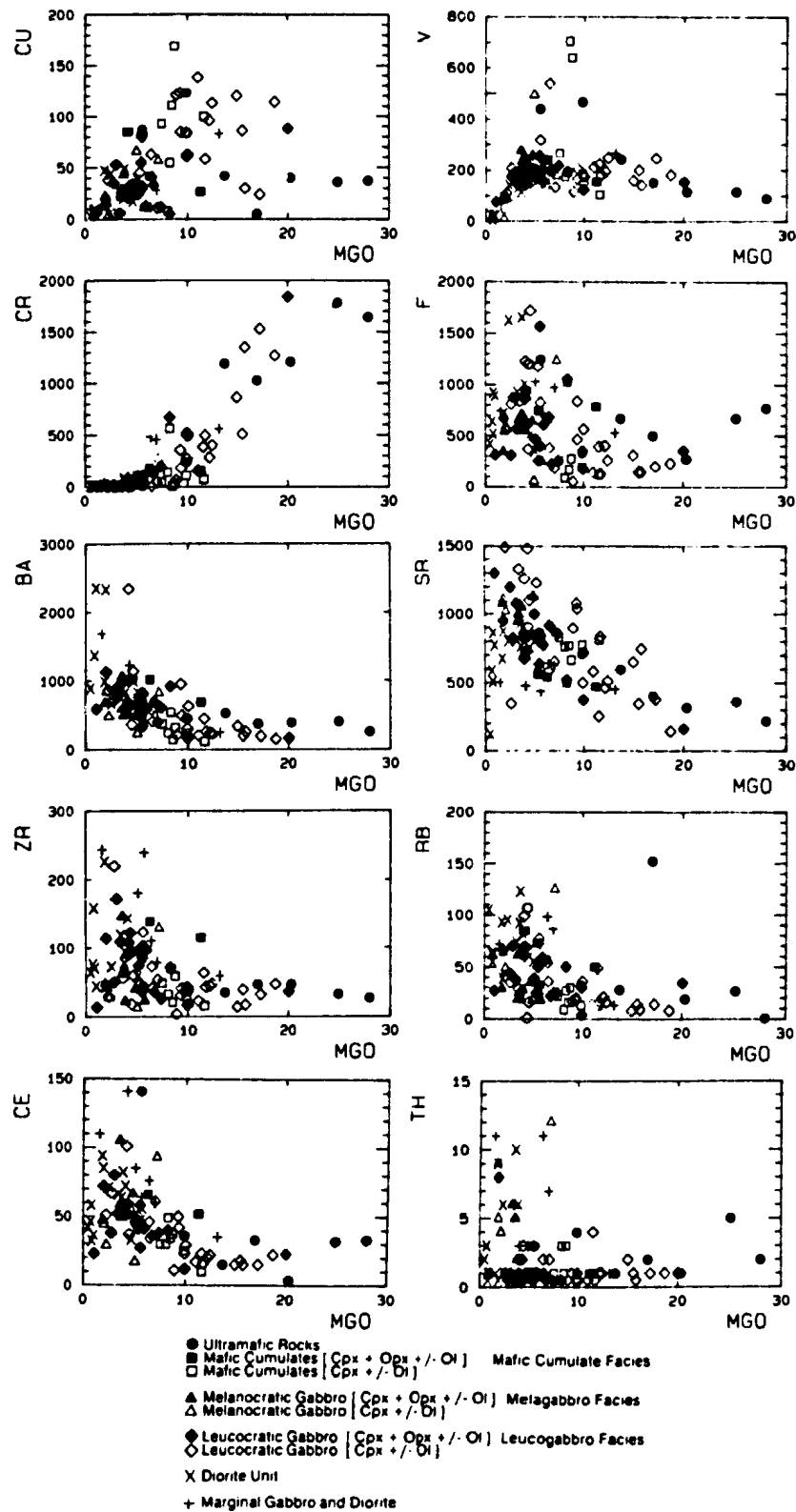
Figure 5.9. Variation of selected trace elements against MgO in the main body of the Adlavik Intrusive Suite. See text for discussion.
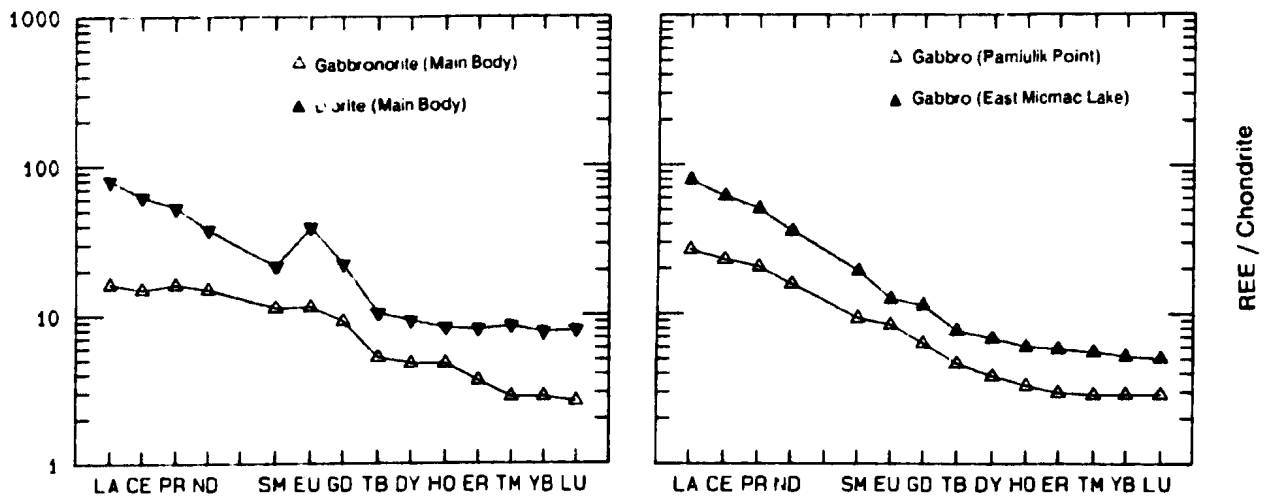
Figure 5.10. Rare Earth Element (REE) patterns for samples from the Adlavik Intrusive Suite. Normalized to chondritic values.

locally has over 4000 ppm Ba. All of these trends are broadly consistent with evolution by fractional crystallization of mafic minerals (olivine, pyroxenes), followed by plagioclase fractionation.

Rare Earth Element (REE) Patterns

REE analyses are available for four samples (Figure 5.10), of which two are from the main body. The mafic sample is a melanocratic olivine-bearing gabbronorite, and shows no Eu anomaly. A small positive Eu anomaly is present in the diorite sample, suggesting that it is a feldspar cumulate, but the overall shape of the pattern is similar to the gabbro. Melanocratic gabbro from Pamiulik Point is almost identical to the main body, but the sample from the East Micmac Lake body is REE - enriched, consistent with its higher SiO_2 content (see also Table 5.2).

5.2.3 Geochemistry of Labradorian Granitoid Rocks

Labradorian granitoid rocks are divided into three groups (A, B and C) to reduce clutter in variation diagrams. Diagrams that use SiO_2 as the X-axis employ a wider horizontal scale for the Mount Benedict Suite (Group A). This group of rocks is probably genetically related to the Adlavik Suite (see later discussion), but it is convenient to describe it in conjunction with siliceous granitoid units.

Major Element Patterns

Major elements follow predictable behaviour patterns (Figure 5.11), and all oxides except Na_2O and K_2O are negatively correlated with SiO_2. The Mount Benedict Intrusive Suite has, predictably, the greatest range of major element compositions, and the Monkey Hill Intrusive Suite the narrowest range. The Mount Benedict Suite has smooth, well-defined trends for all major elements from the least (diorite) to most differentiated (syenite to granite) units. Some (e.g. CaO, Na_2O) are curvilinear, and show inflections at a SiO_2 content of ca. 62%. N/N+K ratio patterns indicate minor disturbance of alkali elements in leucocratic granites of the Monkey Hill Intrusive Suite.

K+N/A (agpaitic index) patterns indicate that there are no Labradorian peralkaline rocks. A/C+N+K (alumina index) patterns indicate that the Monkey Hill Intrusive Suite and Witchdoctor - Burnt Lake Granites are mostly peraluminous, and that the Otter Lake - Walker Lake granitoid is peraluminous above 70% SiO_2. A few high-SiO_2 rocks from the Mount Benedict Suite are also peraluminous.

Ternary AFM and CNK projections (Figure 5.12) are useless for unit discrimination. In the QBF ternary
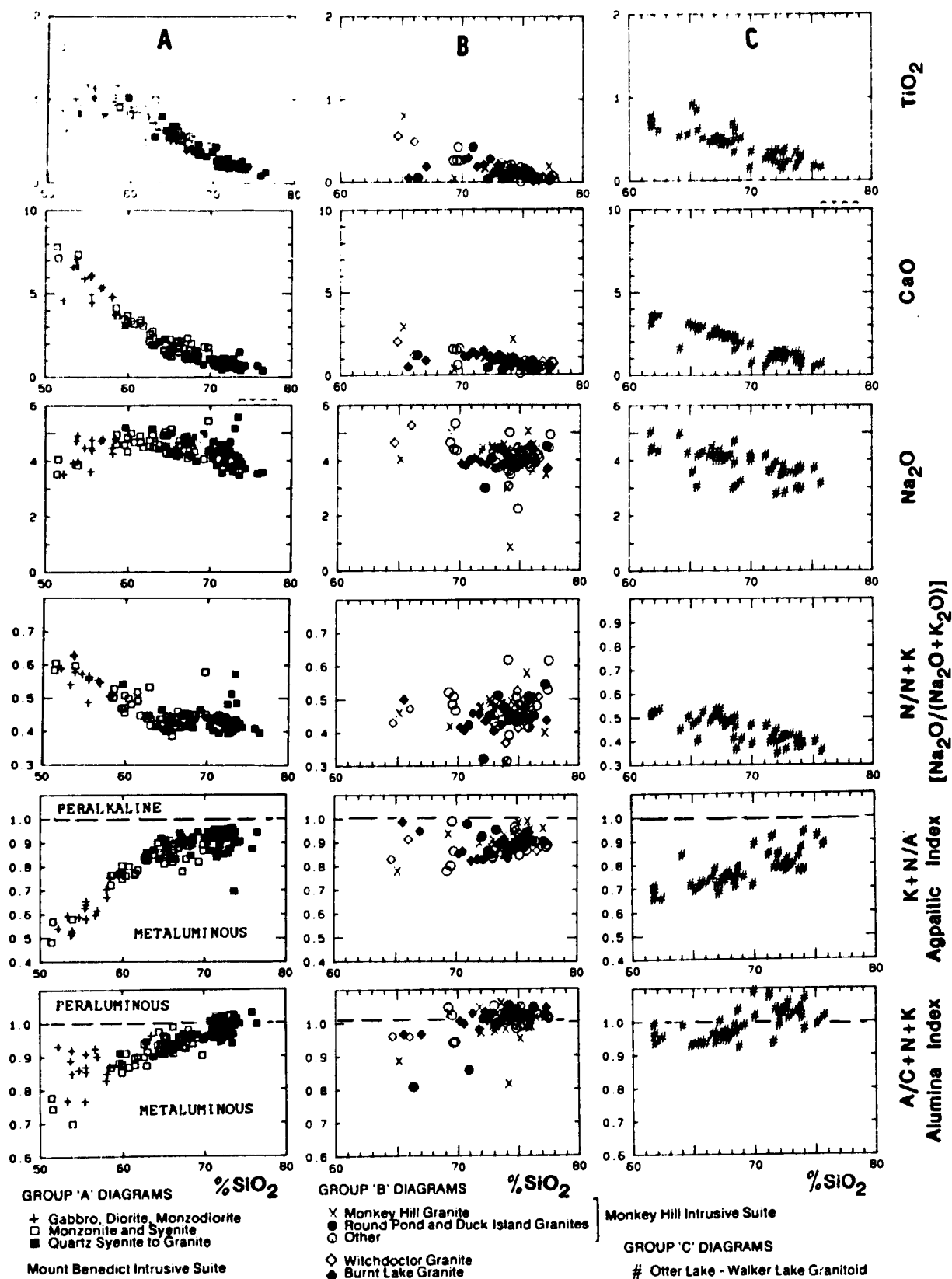
Figure 5.11. Variation of selected major elements and derived ratios
Labradorian granitoid plutonic rocks . See text for discussion.
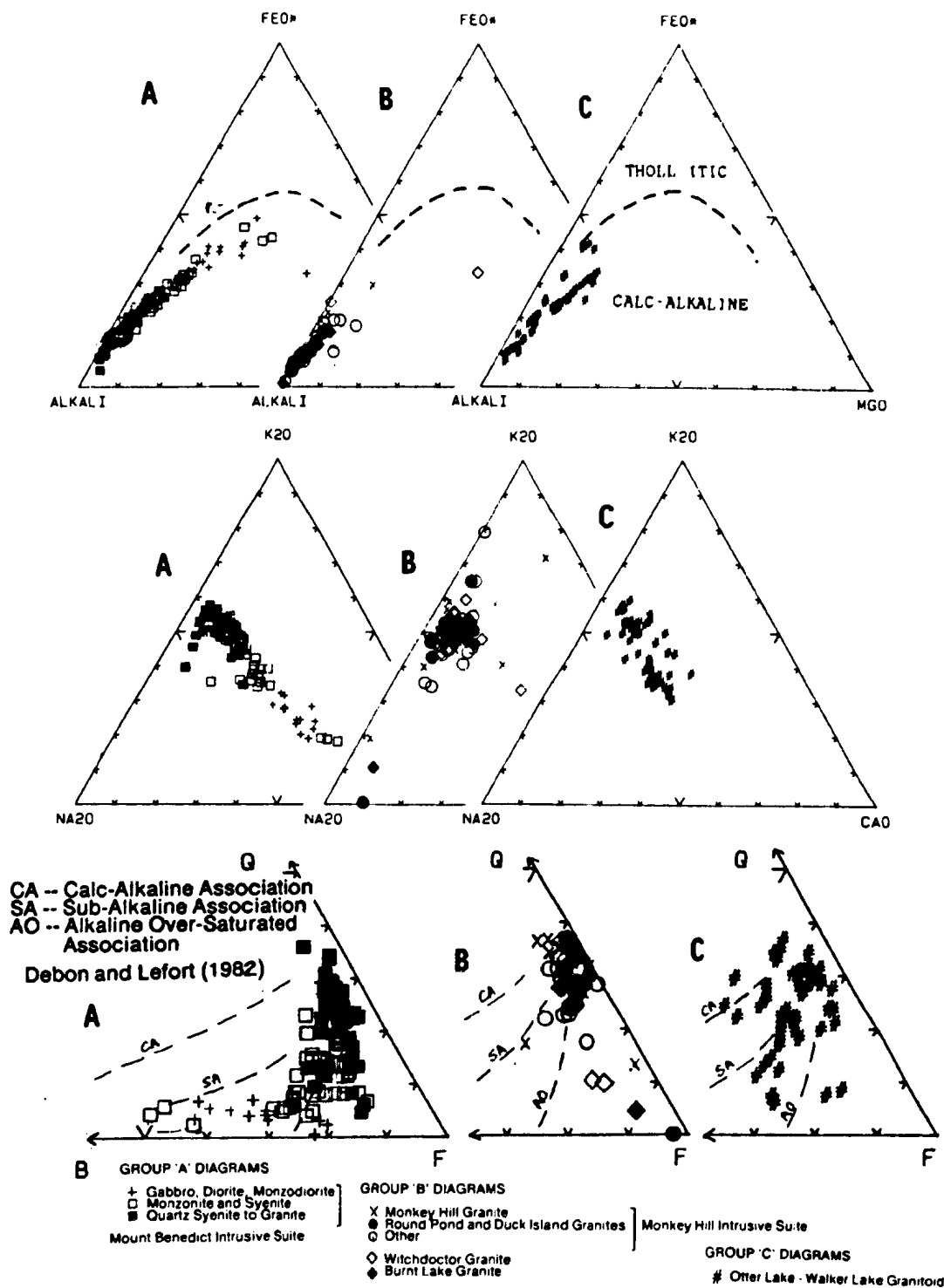
Figure 5.12. AFM, CNK and QBF projections for Labradorian granitoid plutonic units. See text for discussion.

projection (Figure 5.12) of Debon and Lefort (1982), the
Mount Benedict Suite approximates to their alkaline-
oversaturated association, rather than to typical
calc-alkaline associations.

Normative Compositions

In the Quartz - Albite - Anorthite - Orthoclase
quaternary system, only parts of the Mount Benedict
Intrusive Suite contain > 20 % anorthite component. In the
Q-Ab-Or projection (Figure 5.13), this suite has a
well-defined trend that partly corresponds to the location
of plagioclase - K-feldspar cotectic lines f~r high Ab/An
ratios (James and Hamilton, 1969), and terminates in the
ternary minimum area. In detail, there is an inflection in
this trend corresponding to the ca. 62% SiO_2 inflection
noted above; the least evolved part of the suite lies
within the plagioclase field. Granites of the Monkey Hill
Intrusive Suite, Witchdoctor Granite and Burnt Lake Granite
are also clustered around the ternary minimum, although
some samples are scattered towards the albite corner
(reflecting alkali-disturbance).

Trace Element Patterns

Octahedrally Co-ordinated Cation (OCC) Elements : V,
Cu, Cr, Ni and Sc all show similar, uninformative inverse
trends against SiO_2 (e.g. V; Figure 5.14). High levels of
these elements are observed only in parts of the Mount
Benedict ¿ntrusive Suite.

Low Field Strength (LFS) Elements : Incompatible LFS
trace elements (e.g. Rb, Th; Figure 5.14) are positively
correlated with SiO_2, and discriminate the Mount Benedict
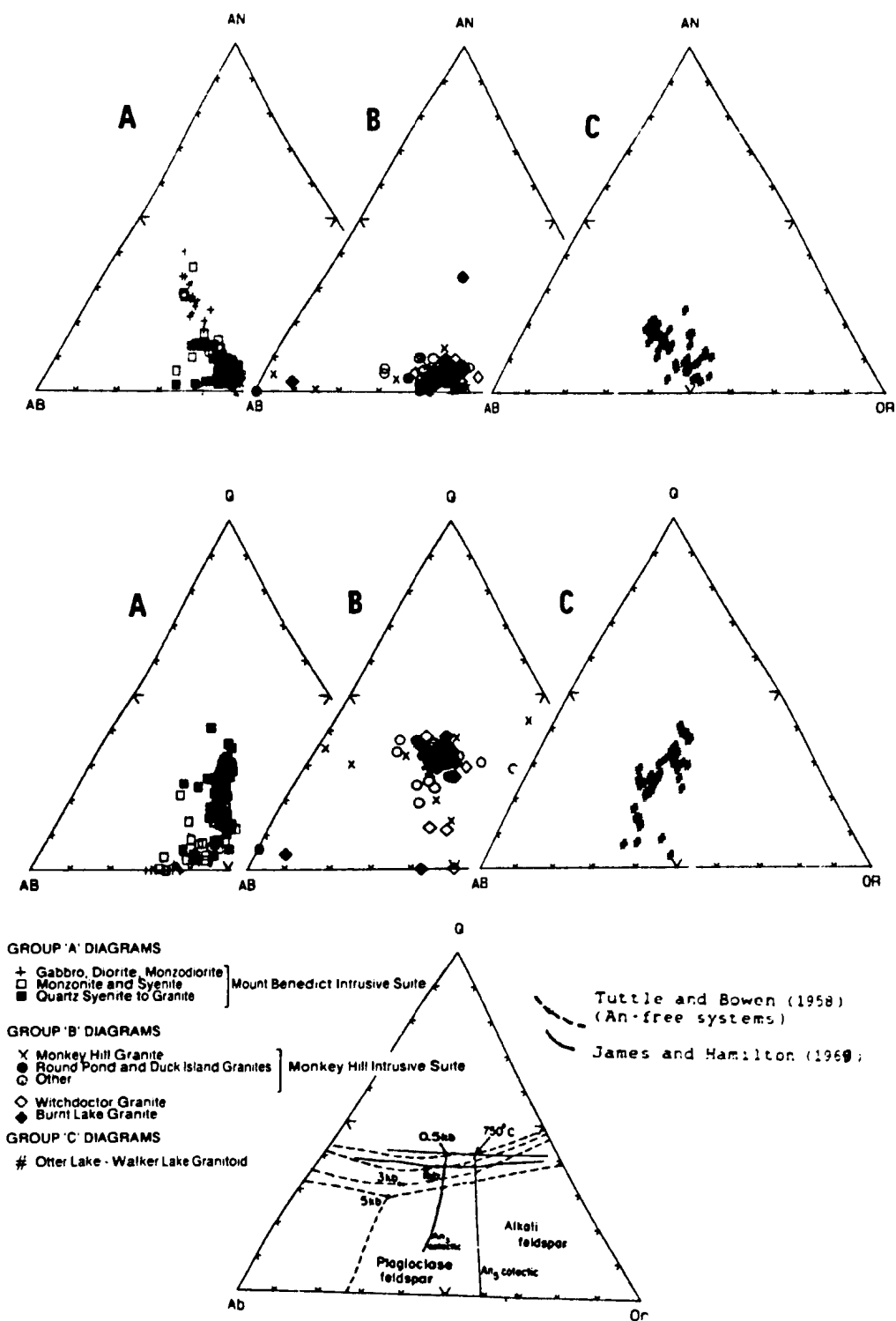
Figure 5.13. Variation of Labradorian granitoid plutonic rocks in the Quartz - Albite - Anorthite - Orthoclase quaternary system. All norms are CIPW. See text for discussion.

Suite from all other Labradorian units. This suite is enriched in Rb and Th (also Cs, Sn, U; not figured) at all SiO_2 levels.

Sr and Ba show generally inverse trends against SiO_2. There is an inflection in the Ba trend for the Mount Benedict Suite at ca. 62% SiO_2; up to this point, Ba remains constant or increases slightly. The Monkey Hill Intrusive Suite and similar granites show rapid depletion of Ba with increasing SiO_2.

High-Field Strength (HFS) Elements : Zr and Nb (Figure 5.15) have convex-upward trends with inflection points at ca. 67% SiO_2 in the Mount Benedict Suite. At higher SiO_2 contents, both are rapidly depleted. High Zr in the 60-67% SiO_2 range distinguishes this suite from other Labradorian units, which mostly contain less than 300 ppm Zr, and have constant or decreasing Zr with increasing SiO_2.

Rare-Earth Elements (REE) : Y and Ce (Figure 5.15) have subhorizontal trends in the Mount Benedict Suite, and are depleted above 67% SiO_2. Absolute REE levels are similar for all Labradorian granitoid rocks, unlike Zr patterns.

Indeterminate Trace Elements : The Mount Benedict Suite is enriched in fluorine (Figure 5.14) relative to all other Labradorian units (except parts of the Adlavik Suite; Table 5.3). The convex-upward F-SiO_2 trend in the Mount Benedict Suite is remarkably similar to the Zr trend. and shows the same inflection at ca. 67% SiO_2. Li (Figure 5.15) does not discriminate between units, and has a scattered distribution in the Monkey Hill Suite and similar
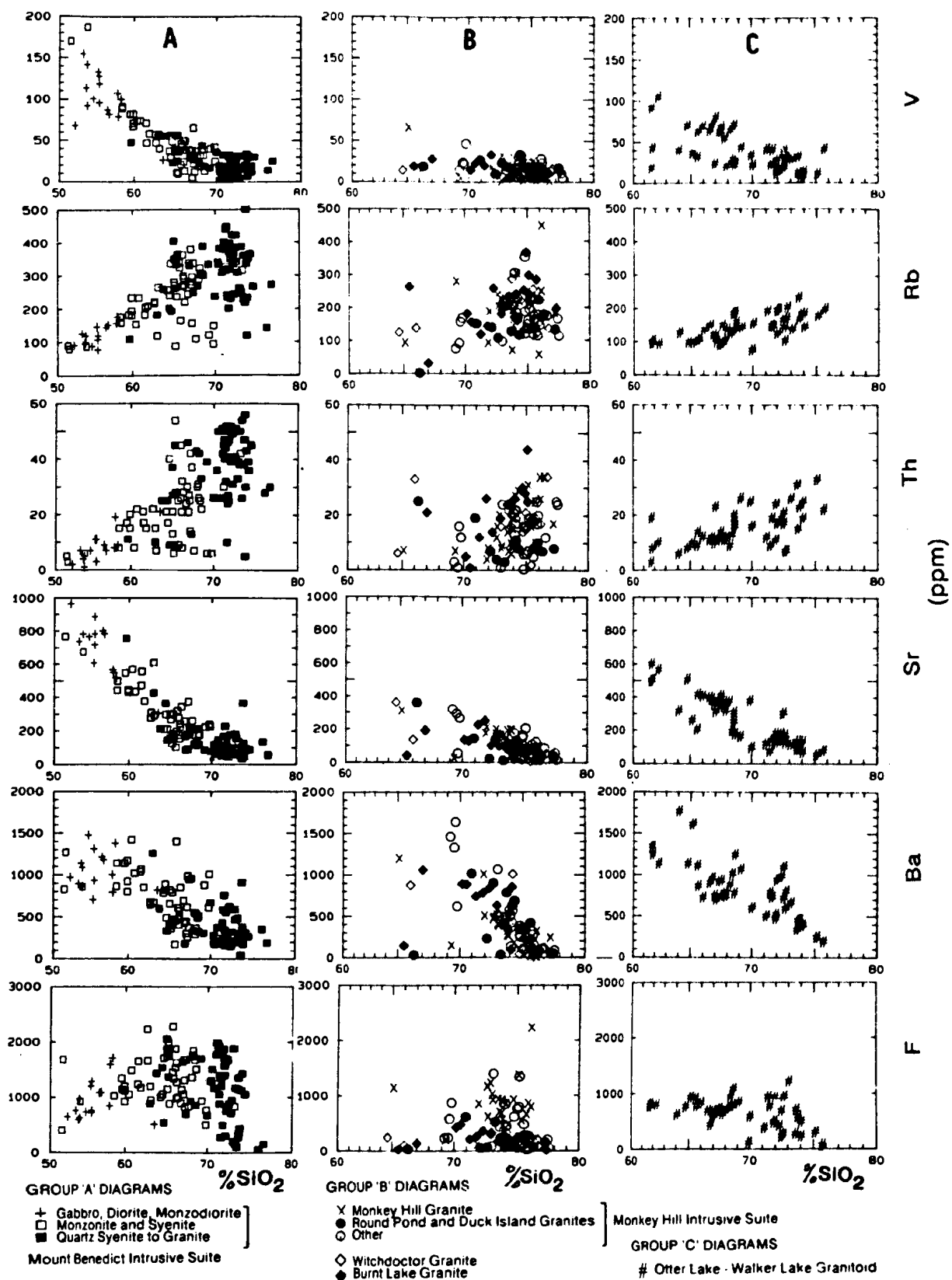
Figure 5.14. V, Rb, Th, Sr, Ba and F versus SiO$_2$ for Labradorian granitoid plutonic rocks. See text for discussion.
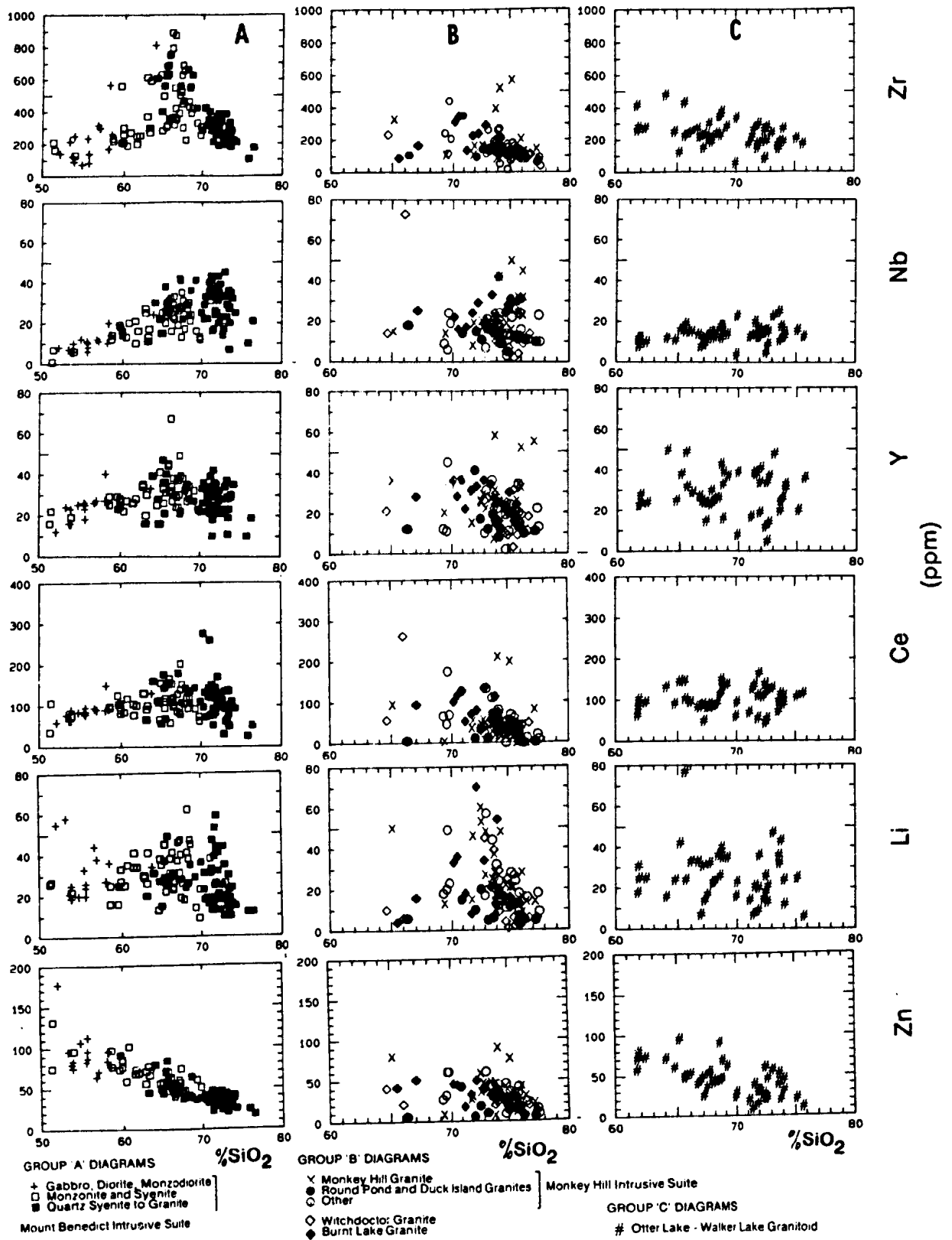
Figure 5.15. Zr, Nb, Y, Ce, Li and F versus SiO$_2$ for Labradorian granitoid plutonic rocks. See text for discussion.

granites. Zn (Figure 5.15) shows trends that resemble those of OCC trace elements in all units, and there is no Zn enrichment at high SiO_2 values.

Trace Element Ratios

K/Rb decreases systematically throughout differentiation in the Mount Benedict Intrusive Suite (Figure 5.16). Variation of K and Rb appears to be partly decoupled in the Monkey Hill Intrusive Suite, which has constant K but variable Rb.

Rb/Sr ratios are similar for all units, but trends are subtly different (Figure 5.16). The Mount Benedict Suite has a well-defined curved trend characterized by initially strong Rb enrichment. All other units have flat or slightly inverse Rb/Sr trends that lack curvature.

The Mount Benedict Suite has a well-defined Ba-Sr trend (Figure 5.16), that is inflected at ca. 500 ppm Sr, corresponding to ca. 62% SiO_2 (Figure 5.14). The monzonite-syenite and syenite-granite units show essentially constant Ba/Sr, and depletion of both elements. The Monkey Hill Suite and similar granites show scattered Ba and Sr distributions. The Otter Lake - Walker Lake trend is similar in orientation to that of the Mount Benedict Suite.

Compared to idealized trends for Rayleigh-type fractionation of common silicates (Figure 5.16, inset), the Rb/Sr trend for the Mount Benedict Suite indicates the influence of plagioclase fractionation (± mafic phases at high Sr contents). The Ba/Sr trend indicates that K-feldspar was also fractionated in more differentiated rocks. This is consistent with the presence of plagioclase and K-feldspar phenocrysts. The inflection point at ca. 62%
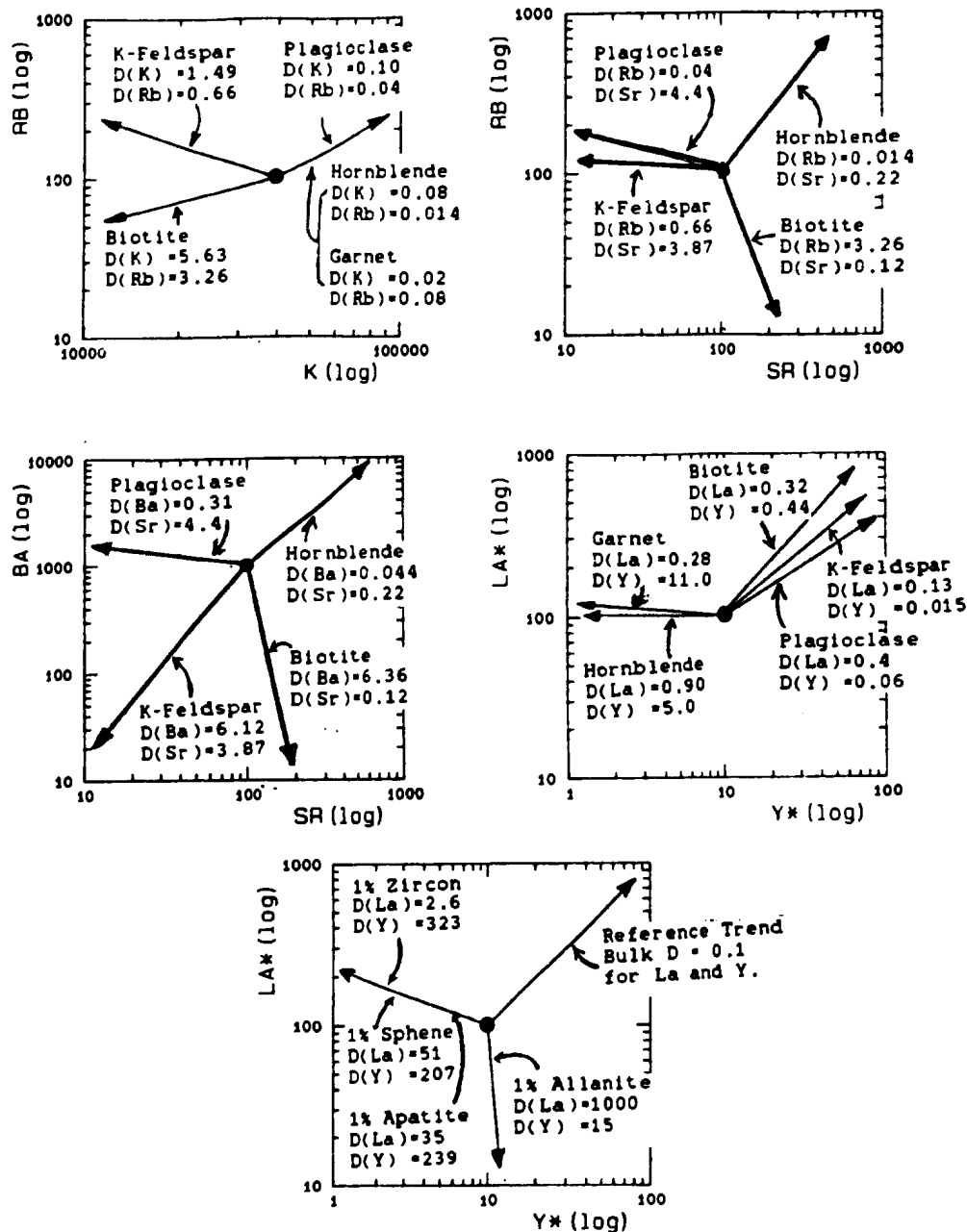
Idealized fractionation trends for Rayleigh fractionation (i.e. perfect separation of crystals and liquid). The La_N/Y_N trends for accessory phases show the effects of only 1% of each phase upon a reference trend where bulk partition coefficients for the remaining 99% of the fractionate are 0.1 for both La and Y. The latter approximates a "normal" path for fractionation of common silicates. Partition coeffcient data from compilations by Arth (1976) and Hanson (1978) for most minerals, and from Gromet and Silver (1983) for allanite and sphene.
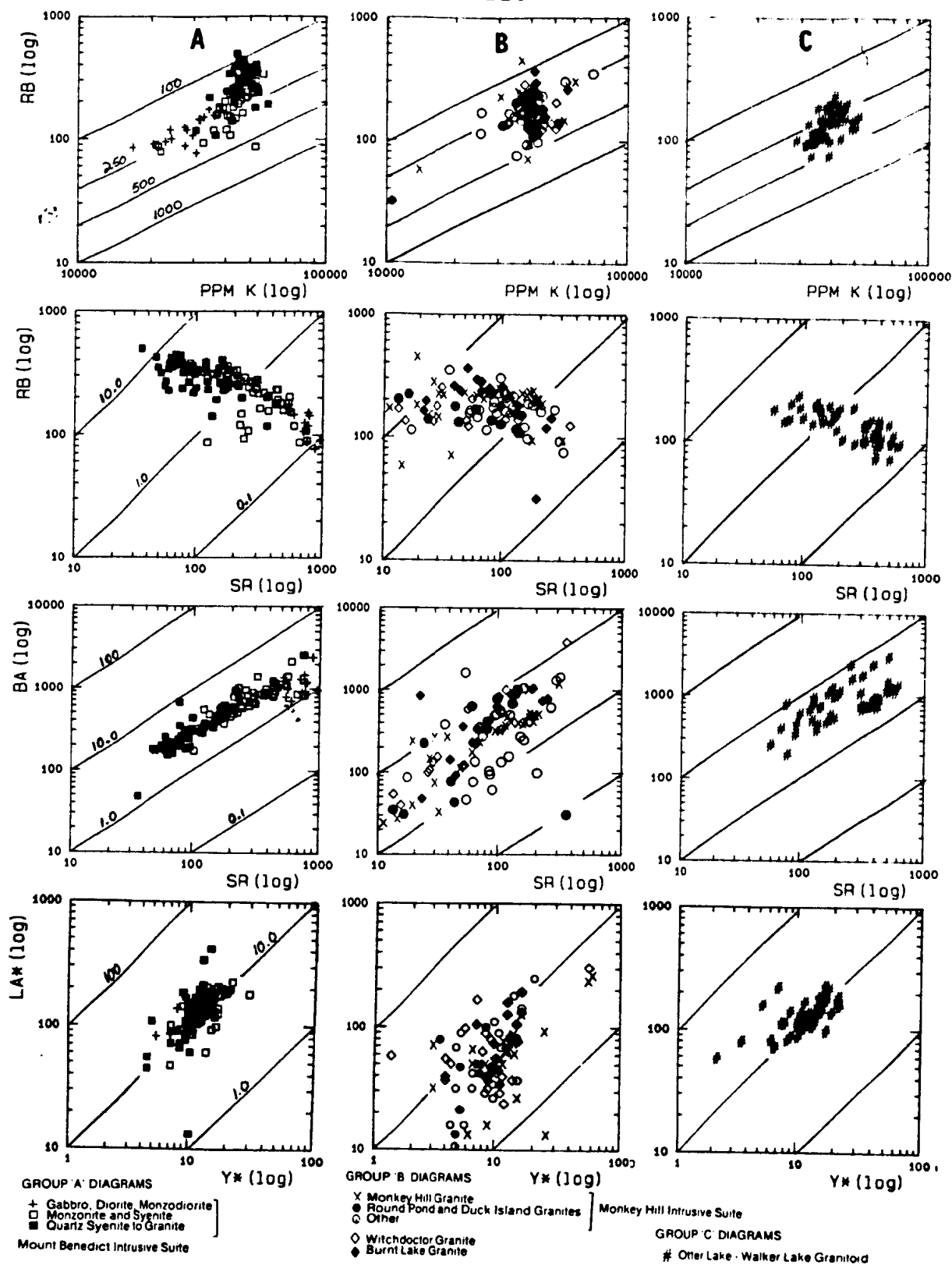
Figure 5.16. Variation in the trace element ratios K/Rb, Rb/Sr, Ba/Sr and La_N/Y_N in Labradorian granitoid plutonic rocks. See opposite for reference fractional crystallization trends.

SiO_2 noted above probably records the onset of significant K-feldspar fractionation. The trends for the Otter Lake - Walker Lake granitoid similarly indicate fractionation of both feldspars, consistent with the observed phenocryst assemblages.

La_N/Y_N (chondrite normalized) ratios (Figure 5.16) are relatively constant at 10-20 in the Mount Benedict Intrusive Suite, and there is little absolute difference between the three units. La and Y abundances are scattered in the Monkey Hill Intrusive Suite; the pattern suggests La (thus LREE) depletion.

Rare Earth Element (REE) Patterns

Three samples from contrasting units of the Mount Benedict Suite have similar REE patterns and abundances (Figure 5.17) . The least evolved pattern resembles the Adlavik Intrusive Suite REE pattern (Figure 5.10). A strong Eu anomaly in the more evolved rocks indicates feldspar fractionation.

Granites of the Monkey Hill Intrusive Suite have varied REE patterns (Figure 5.18). The main body and Little Monkey Hill Granite have low total REE (< 100 x chondrite) and modest negative Eu anomalies. Excluding Eu, they are most depleted in Dy and Ho, and have dish-shaped patterns. The Round Pond Granite has strong LREE and MREE depletion, and inverse HREE fractionation. MacDougall (1988), in a detailed study of the Round Pond area, reported that this depletion intensifies with increasing SiO_2. He suggested that the REE were lost to a hydrothermal fluid. As these granites have low total REE, even minimal extraction of allanite or monazite (in which REE are stochiometric components) would have drastic effects, as effective
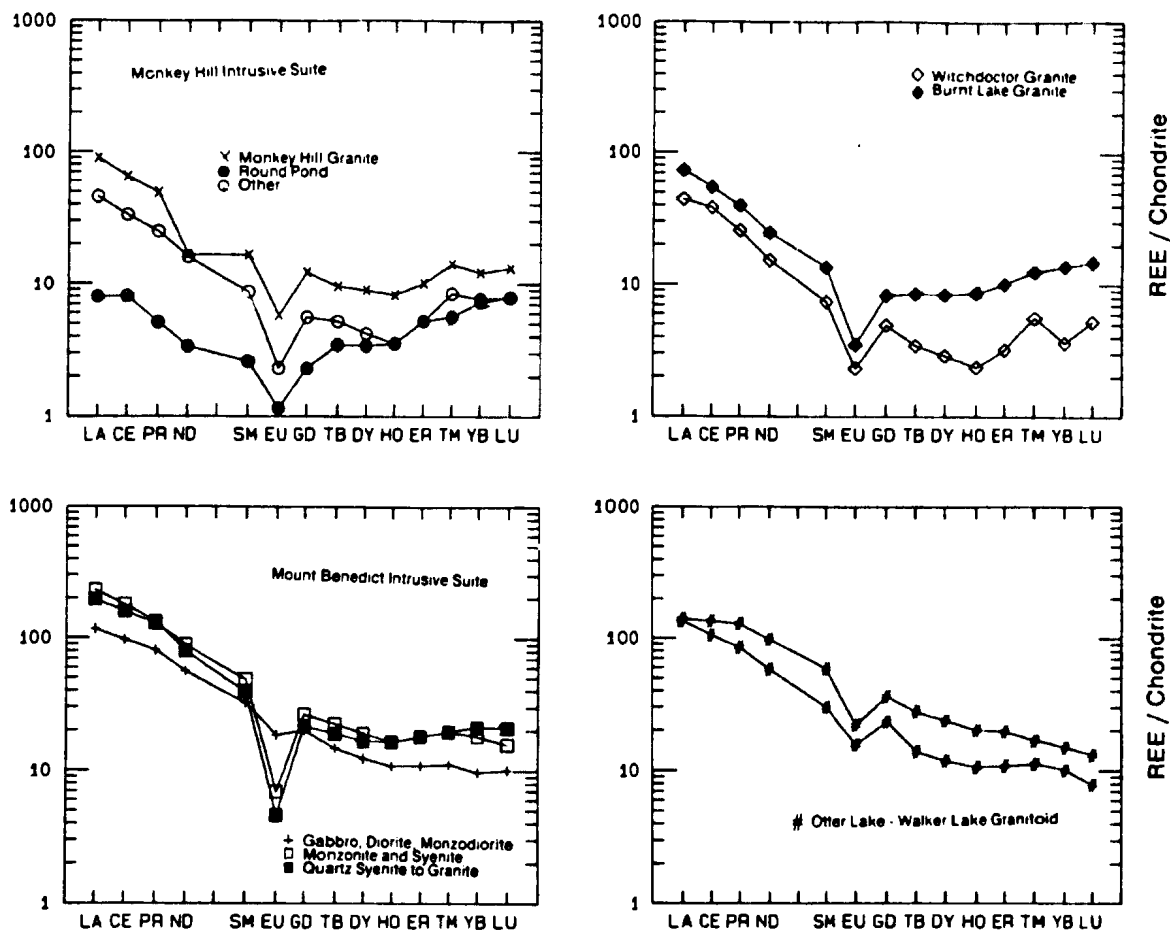
Figure 5.17 . Rare Earth element (REE) patterns for representative
Labradorian granitoid plutonic rocks. Values are normalized to
chondritic values (listed in Appendix C).

partition coefficients are inversely proportional to liquid concentrations (e.g. Miller and Mittlefehldt, 1982; Gromet and Silver, 1983). Depletion is, however, not confined to the REE (Table 5.2), and normal igneous processes cannot account readily for the overall trace element pattern of the Round Pond Granite. The Witchdoctor and Burnt Lake granites have closely similar REE patterns; the former has the same "valley" at Dy and Ho. This feature indicates compatible behaviour of some HREE, which may indicate effects from hornblende or (more likely) garnet as a liquidus or residual phase; It is most obvious in the slightly garnetiferous Witchdoctor Granite. The affinity of Zircon or sphene for HREE (e.g. Arth, 1976; Watson, 1982; Gromet and Silver, 1983) suggests that these minerals might also contribute to such a pattern. The Otter Lake - Walker Lake Granitoid has unremarkable REE patterns, consistent with its wide range of other totally unremarkable features.

5.3 SUMMARY AND DISCUSSION

Contrasts Between Labradorian and Makkovikian Plutonic Associations

Labradorian plutonic rocks differ from their Makkovikian counterparts in several respects. Firstly, the Makkovikian assemblage does not include layered mafic intrusions such as the Adlavik Intrusive Suite, although such rocks might be present below the present level of exposure (there are, for example, mafic inclusions in the border zone of the Numok Suite). Secondly, Labradorian granitoid rocks do not evolve to the marginal peralkaline compositions typical of syn- and post-tectonic Makkovikian gramites (Chapters 3 and 4). They are instead mostly of slightly peraluminous character, especially above 70% SiO_2.

These contrasts are summarized in Table 5.4, which lists mean compositions for units of similar SiO_2 content in both assemblages. At a given SiO_2 value, Labradorian intrusions are poorer in fluorine, HFS (e.g. Zr, Nb, Hf) elements and REE (e.g. La, Ce, Sm, Yb). They show no sign of Zn enrichment at higher SiO_2 contents. LFS element abundances are similar in both assemblages, except for the Mount Benedict Suite, which is enriched relative to all other units of equivalent or higher SiO_2. This suite also has F and Zr contents (particularly at 62-67% SiO_2) that approach those of some Makkovikian units, but is depleted at higher SiO_2 contents.

It must be stressed that, in spite of these differences, Makkovikian and Labradorian plutonic rocks exhibit extensive geochemical overlap. It is therefore difficult to classify single samples or small sample suites on the basis of geochemistry alone.

Table 5.4. Comparison of average compositions for selected syn-tectonic and post-tectonic Makkovikian plutonic suites, and Labradorian units of similar SiO_2 content.

UNIT	10		20		21		42-44		11		23-26	
n1	15		57		40		137		97		197	
n2	5		12		6		62		23		142	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	63.32	1.27	62.31	4.27	65.52	3.92	66.40	6.28	73.58	2.98	71.29	4.71
TiO2	0.88	0.06	0.78	0.29	0.63	0.29	0.50	0.31	0.29	0.19	0.31	0.27
Al2O3	15.81	0.24	16.69	1.49	15.07	1.21	15.50	1.69	12.67	1.15	13.68	1.55
Fe2O3	1.79	0.37	1.72	0.75	1.44	0.61	1.27	0.62	1.24	0.70	1.05	0.74
FeO	3.06	0.73	3.41	1.12	3.66	1.75	2.07	1.45	1.39	1.17	1.68	1.47
MnO	0.10	0.01	0.12	0.05	0.15	0.07	0.07	0.04	0.06	0.02	0.06	0.06
MgO	1.25	0.42	1.22	0.87	0.40	0.29	0.96	1.19	0.19	0.25	0.36	0.50
CaO	2.95	0.48	2.92	1.30	1.76	0.71	2.08	1.84	0.82	0.56	1.14	1.04
Na2O	4.27	0.25	4.57	0.41	4.51	0.57	4.38	0.42	4.00	0.48	4.09	0.86
K2O	4.75	0.49	5.14	1.09	5.81	0.67	5.27	0.98	4.85	0.64	5.12	1.10
P2O5	0.26	0.03	0.24	0.14	0.15	0.13	0.15	0.18	0.05	0.05	0.07	0.09
LOI	0.63	0.23	0.58	0.35	0.46	0.23	0.85	0.30	0.45	0.22	0.67	0.37
TOTAL	99.07		99.67	0.00	99.54		99.49		99.57		99.52	

(ppm)	Trace Elements											
Li	22.7	5.7	21.0	9.7	13.0	7.6	28.5	11.3	14.9	11.7	25.0	23.5
F	860.5	212.7	928.9	436.3	427.8	270.3	1229.8	524.6	1029.9	803.8	1420.0	1141
Sc	9.6	1.7	10.5	2.1	11.0	3.8	4.0	2.3	1.4	0.9	3.1	4.1
V	74.6	19.6	55.9	37.5	17.7	10.0	44.3	40.6	15.9	13.4	23.3	29.2
Cr	5.5	3.5	7.0	9.9	3.4	2.4	14.0	32.0	4.7	3.8	5.1	6.5
Ni	2.6	1.9	3.7	4.7	1.1	0.5	5.1	16.3	1.3	1.2	2.2	3.9
Cu	9.1	3.8	13.6	9.5	6.4	3.1	19.3	23.5	3.9	3.9	9.3	38.4
Zn	74.1	8.5	86.3	23.4	114.3	44.2	54.3	24.6	77.1	29.9	75.1	69.6
Ga	18.3	1.2	20.5	2.9	21.6	6.3	11.0	5.0	16.5	6.8	16.9	8.6
Rb	126.4	24.2	121.9	47.9	110.8	54.5	260.5	99.6	153.5	47.1	178.4	65.0
Sr	327.6	39.0	329.4	166.6	108.5	77.0	276.6	258.1	60.8	77.5	111.7	130.2
Y	36.5	1.9	39.2	13.6	53.5	19.9	28.3	8.1	70.9	28.9	55.4	43.8
Zr	236.6	83.2	486.3	255.9	794.8	411.2	356.3	174.2	387.0	151.8	491.5	558.5
Nb	14.2	1.1	19.1	8.5	21.3	6.9	23.7	10.1	27.9	14.0	26.0	21.0
Mo	4.3	0.5	4.1	1.0	3.4	1.1	4.5	2.4	3.7	1.9	4.3	7.7
Sn	1.0	0.0	2.7	2.7	1.3	0.5	6.9	4.3	3.5	2.5	5.8	9.9
Cs	1.3	1.2	1.0	1.7	0.7	0.4	9.6	4.7	0.6	0.4	1.2	1.0
Ba	1424.0	116.2	1099.0	558.0	787.7	542.1	612.5	440.7	453.1	411.7	501.9	382.6
La	53.3	4.9	64.8	31.7	77.2	26.4	52.6	18.7	76.6	33.3	90.7	111.7
Ce	102.7	6.1	131.0	63.2	156.4	54.7	108.8	37.3	158.7	65.7	178.7	197.0
Sm	9.2	0.8	13.3	3.1	14.5	3.8	7.4	1.8	12.6	3.5	13.1	10.4
Yb	2.5	0.0	3.8	2.1	5.3	0.0	4.4	0.9	7.7	3.2	6.6	4.7
Hf	8.0	1.2	11.9	3.5	14.3	5.0	10.8	3.4	12.1	3.1	13.3	13.3
Pb	15.9	3.9	15.9	6.6	15.8	7.1	19.9	7.9	20.3	10.4	37.3	205.3
Th	9.2	3.0	9.1	10.7	5.1	4.8	27.7	16.7	15.2	9.6	18.3	20.5
U	4.8	0.9	3.1	1.7	2.4	1.4	8.1	4.4	4.7	3.0	5.8	7.0

(wt%)	partial CIPW norms											
Q	12.25	1.76	8.02	6.40	10.77	7.74	15.19	9.84	29.80	6.01	24.90	9.23
C	0.00	0.00	0.05	0.18	0.02	0.05	0.07	0.19	0.02	0.06	0.12	0.23
Or	28.50	2.93	31.47	4.81	32.52	5.39	31.52	5.81	28.89	3.89	30.38	5.96
Ab	36.71	2.01	38.96	3.48	40.28	5.85	37.51	3.57	34.11	4.02	34.90	7.35
An	10.08	1.50	9.37	4.48	5.28	3.78	7.01	6.36	2.30	2.27	3.66	2.94
Di	2.88	1.35	2.85	1.48	3.52	2.25	1.98	2.21	1.08	0.87	1.28	2.82
Hy	4.65	1.72	4.53	2.26	3.22	2.08	3.07	2.93	1.22	2.00	2.15	2.26
ol	0.00	0.00	0.41	1.09	0.61	1.36	0.37	1.71	0.00	0.00	0.03	0.26
Mt	2.64	0.55	2.41	0.96	2.06	0.78	1.81	0.93	1.58	0.75	1.38	1.00
Il	1.69	0.12	1.48	0.56	1.21	0.49	0.97	0.60	0.54	0.36	0.61	0.52

KEY TO UNITS (STM - syn-tect Makkovikian; PTM - post-tect Makkovikian; L - Labradorian)
10 -- Long Island Quartz Monzonite (all data) [STM]
20 -- Numok Intrusive Suite (Monzonite to Quartz Monzonite) [PTM]
21 -- Numok Intrusive Suite (Syenite to Quartz Syenite) [PTM]
42-44 -- Mount Benedict Intrusive Suite (all data) [L]
11 - Kennedy Mountain Intrusive Suite (all data, unaltered) [STM]
23-26 -- Strawberry Intrusive Suite (all data) [PTM]

n1 -- Number of analyses for all elements except those listed below
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf

Table 5.4 (continued)

UNIT	27-29		13.0		45		46-47		30		48	
nl	82		4		70		34		79		49	
n2	66				57		29		13		11	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	72.12	2.93	72.73	1.26	73.50	4.42	73.24	3.22	70.11	5.15	68.54	4.42
TiO2	0.32	0.19	0.16	0.09	0.14	0.12	0.15	0.11	0.39	0.22	0.44	0.20
Al2O3	13.22	1.34	14.66	0.44	13.49	1.18	13.98	1.49	14.43	1.74	14.98	1.62
Fe2O3	1.21	0.57	0.64	0.44	1.08	3.23	0.61	0.45	1.16	0.55	1.20	0.61
FeO	1.44	0.87	0.66	0.29	0.70	1.56	0.62	0.31	1.49	0.97	1.87	1.01
MnO	0.06	0.04	0.03	0.01	0.05	0.04	0.04	0.01	0.06	0.04	0.06	0.03
MgO	0.18	0.17	0.65	0.27	0.21	0.24	0.18	0.13	0.50	0.84	0.86	0.54
CaO	0.88	0.47	0.99	0.03	0.76	0.44	0.78	0.36	1.36	1.20	2.04	1.02
Na2O	3.97	0.61	5.06	0.93	4.26	1.07	4.27	1.11	4.28	0.75	3.89	0.55
K2O	5.47	0.90	3.34	1.46	4.72	1.22	4.98	0.87	5.11	1.01	4.70	0.62
P2O5	0.04	0.04	0.06	0.02	0.03	0.03	0.02	0.03	0.10	0.08	0.15	0.09
LOI	0.53	0.20	0.93	0.29	0.58	0.27	0.50	0.13	0.58	0.29	0.77	0.24
TOTAL	99.44		99.91		99.48		99.37		99.57		99.50	
(ppm)												
Li	13.9	11.7	11.5	1.7	20.5	13.6	20.7	19.8	14.8	6.2	25.7	12.5
P	1244.6	935.7	187.5	68.4	511.7	436.6	177.7	120.6	688.5	462.5	679.1	257.1
Sc	3.8	5.3			1.4	1.2	1.9	1.2	2.4	0.9	6.8	2.4
V	12.8	7.7	21.5	8.5	17.4	18.1	14.6	6.8	21.5	17.1	44.6	30.2
Cr	3.7	2.9	7.5	5.7	4.0	6.4	3.5	3.8	4.8	13.7	6.5	7.0
Ni	1.5	1.8	3.0	2.7	1.4	1.3	1.7	2.1	2.6	7.9	2.1	3.0
Cu	6.0	9.2	3.5	1.3	9.2	20.2	3.8	3.7	6.3	6.1	9.1	18.7
Zn	89.6	59.6	29.3	3.9	34.9	30.5	28.8	10.9	54.8	42.8	46.9	21.4
Ga	21.4	10.0	6.8	1.7	12.0	6.6	11.7	5.8	15.2	5.2	12.8	4.1
Rb	172.5	44.1	96.5	41.0	181.7	71.7	191.1	68.2	127.8	51.8	140.5	38.7
Sr	61.2	65.8	273.5	47.5	134.5	210.4	87.1	75.8	160.7	151.6	277.7	154.8
Y	74.4	32.8	5.8	1.7	26.5	23.0	25.3	20.2	42.5	17.2	28.2	10.2
Zr	675.7	439.3	88.0	38.0	160.1	99.3	185.6	172.3	368.8	210.3	240.0	83.8
Nb	29.3	11.1	2.0	0.0	17.2	8.5	20.8	13.6	19.1	7.2	13.6	4.4
Mo	4.3	2.3	2.0	0.0	84.5	578.7	28.1	142.9	3.7	1.2	3.2	1.2
Sn	4.0	2.6			2.9	2.3	2.4	2.1	2.7	2.7	3.9	3.3
Cs	1.1	0.7			2.2	2.1	1.9	1.3	0.7	0.6	4.1	1.8
Ba	329.6	260.1	912.5	446.6	391.2	360.5	519.0	675.5	660.8	482.6	961.5	542.3
La	122.8	62.6	13.8	4.6	22.1	21.4	30.9	22.3	63.1	30.2	50.6	14.8
Ce	247.2	121.1	19.0	11.6	45.4	43.8	63.2	45.7	126.8	59.2	100.1	28.5
Sm	20.8	9.8			4.4	4.0	4.2	1.9	10.4	3.9	9.3	3.0
Yb	8.8	4.3			3.9	3.6	2.8	0.6	4.2	2.0	2.5	0.0
Hf	19.1	10.3			5.6	3.0	5.6	1.5	10.1	3.0	12.5	21.1
Pb	24.5	13.5	12.5	7.9	22.6	9.2	26.8	11.5	17.6	11.2	16.8	8.1
Th	18.9	8.0	1.8	1.0	13.6	8.5	19.1	9.2	13.0	9.6	14.8	7.3
U	5.5	2.3	1.7	0.5	6.0	5.1	7.4	5.0	4.5	2.6	4.0	2.4
(wt%)												
Q	26.22	7.51	27.56	2.39	28.99	5.57	26.82	9.65	22.16	9.88	22.14	8.29
C	0.10	0.70	0.98	0.48	0.25	0.24	0.26	0.21	0.06	0.14	0.26	0.36
Or	32.64	5.34	19.88	8.64	27.82	7.14	29.78	5.21	30.45	6.00	28.14	3.71
Ab	33.79	5.15	43.23	8.08	36.63	8.56	36.39	9.20	36.54	6.34	33.29	4.70
An	1.90	1.64	4.84	0.26	3.22	1.70	3.61	1.64	4.97	4.19	8.95	4.23
Di	1.62	1.35	0.00	0.00	0.25	0.72	0.16	0.41	1.11	1.66	0.49	0.74
Hy	0.96	1.05	2.12	0.72	0.86	0.99	0.87	0.62	1.81	1.34	3.77	2.10
Ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	1.60	0.00	0.00
Mt	1.63	0.77	0.94	0.64	1.29	4.96	0.82	0.46	1.60	0.82	1.76	0.90
Il	0.62	0.36	0.31	0.17	0.26	0.22	0.30	0.22	0.74	0.43	0.85	0.38

KEY TO UNITS (STM - syn-tect Makkovikian; PTM - post-tect Makkovikian; L - Labradorian)
27-29 -- Lanceground Intrusive Suite (all data) [PTM]
13 -- Brumwater Granite [STM]
45 -- Monkey Hill Intrusive Suite (all data) [L]
46-47 -- Witchdoctor and Burnt Lake Granites (all data) [L]
30 -- Big River Granite (all data) [PTM]
48 -- Otter Lake - Walker Lake Granitoid (all data) [L]

n1 -- Number of analyses for all elements except those listed below
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf

Evolution of The Adlavik Intrusive Suite

The Adlavik Intrusive Suite is a multiphase mafic
intrusion that evolved via crystal accumulation processes.
Field relationships within the main body indicate at least
two (and probably many more) pulses of mafic magmatism, and
it likely represents the proverbial "periodically refilled,
periodically tapped, continously evolving magma chamber"
(words of O'Hara, 1977).

Although reconstruction is difficult, normative
mineralogical variations (Figure 5.7) indicate that higher
levels are dominated by gabbro (± olivine), that is poorer
in SiO_2, K_2O and incompatible elements than a lower
gabbronorite (± olivine) sequence. This suggests that the
parental magma(s) were derived from a fractionating magma
chamber at much deeper levels (the general similarity of
trace element patterns in all argues against two radically
different sources). The gabbronorite sequence may have been
derived from the upper, fractionated, portion of such a
body, whereas the overlying gabbro sequence originated at
deeper, less fractionated levels.

Once emplaced, the Adlavik Suite magmas evolved by
fractionation of olivine and pyroxenes, and a later
plagioclase-dominated assemblage. Residual liquids were in
some cases trapped within cumulate zones (bounded by
viscosity or density contrasts ?), where they crystallized
to form the pegmatite facies. Some residual magmas migrated
on an intrusion-wide scale to form the more potassic
members of the diorite unit, but much of this is probably a
plagioclase cumulate with variable amounts of trapped
liquid. Volatile concentration and circulation as a
consequence of crystallization (and perhaps ascent) led to
widespread transformation of earlier pyroxenes, and
crystallization of primary hornblende from more
fractionated liquids.

Evolution of The Mount Benedict Intrusive Suite

Geochemical trends in the Mount Benedict Suite are readily interpreted in terms of fractional crystallization, and provide constraints for numerical modelling (see below).

Rb/Sr and Ba/Sr trends (Figure 5.17) indicate that plagioclase, K-feldspar and mafic minerals were the dominant liquidus phases, consistent with the observed phenocryst assemblages. Plagioclase phenocrysts occur in all but the most evolved rocks, and accumulated in the diorite unit. Initial strong Rb enrichment (Figure 5.7) is characteristic of plagioclase ($\pm$ mafic mineral) fractionation, as is the antithetic behaviour of Ba and Sr. Both features predominate below 62% SiO_2 (Figure 5.15). The inflection of Ba trends at this point indicates the onset of K-feldspar crystallization; constant Ba/Sr during subsequent evolution suggests that both feldspars continued to crystallize in roughly constant proportions (assuming that distribution coefficients remained constant). The inflection at ca. 62% SiO_2 also marks the point at which the evolving liquid reached the plagioclase - alkali-feldspar cotectic line (Figure 5.13).

The convex-upward Zr-SiO_2 trend (Figure 5.16) defines the appearance of a Zr-rich phase (probably zircon) at ca. 67% SiO_2. The close correspondence between Zr and F trends suggests that Zr solubility may have been reduced by loss of fluorine from the magma, or that both were affected by a third factor, perhaps an increase in melt polymerization. The generally flat REE and Y trends indicate that these elements were buffered at an earlier stage, probably by accessory phases such as sphene, which locally cores hornblende. Depletion in Th and REE (Figures

5.15, 5.16) at the highest SiO_2 contents may indicate the effects of allanite fractionation (c.f. Michael, 1982; Miller and Mittlefehldt, 1982).

Relationship Between The Adlavik and Mount Benedict Intrusive Suites

The Adlavik and Mount Benedict Intrusive Suites are viewed here as complementary associations, i.e., the mafic and plagioclase cumulates of the Adlavik Suite represent material removed from a mafic parental magma to produce the more evolved rocks of the Mount Benedict Suite. The diorite unit in the Mount Benedict Suite includes plagioclase cumulates that resemble leucogabbro and diorite of the Adlavik Suite. Their presence at the margins of the suite, and at low topographic elevations suggests a crude layering or zonation, and suggests that mafic rocks may occur below the present level of exposure. The mafic rocks at Pamiulik Point, although grouped above with the Adlavik Suite, possibly represent some of this material.

There are indications that the Mount Benedict Intrusive Suite is a crudely layered body. In the field, this is suggested by the preferred occurrence of the most evolved syenite and granite at high elevations. Compositional layering or zonation is also indicated by geochemical variation with elevation (Figure 5.18). Chemical - elevation correlations are far from perfect, but the most evolved compositions are dominant at higher altitudes.

The Adlavik and Mount Benedict Suites also define smooth and continous geochemical trends against SiO_2 (Figure 5.19), with some scatter at low SiO_2 values that reflects the presence of cumulate rocks. The strong incompatible element enrichment in the evolved rocks of the
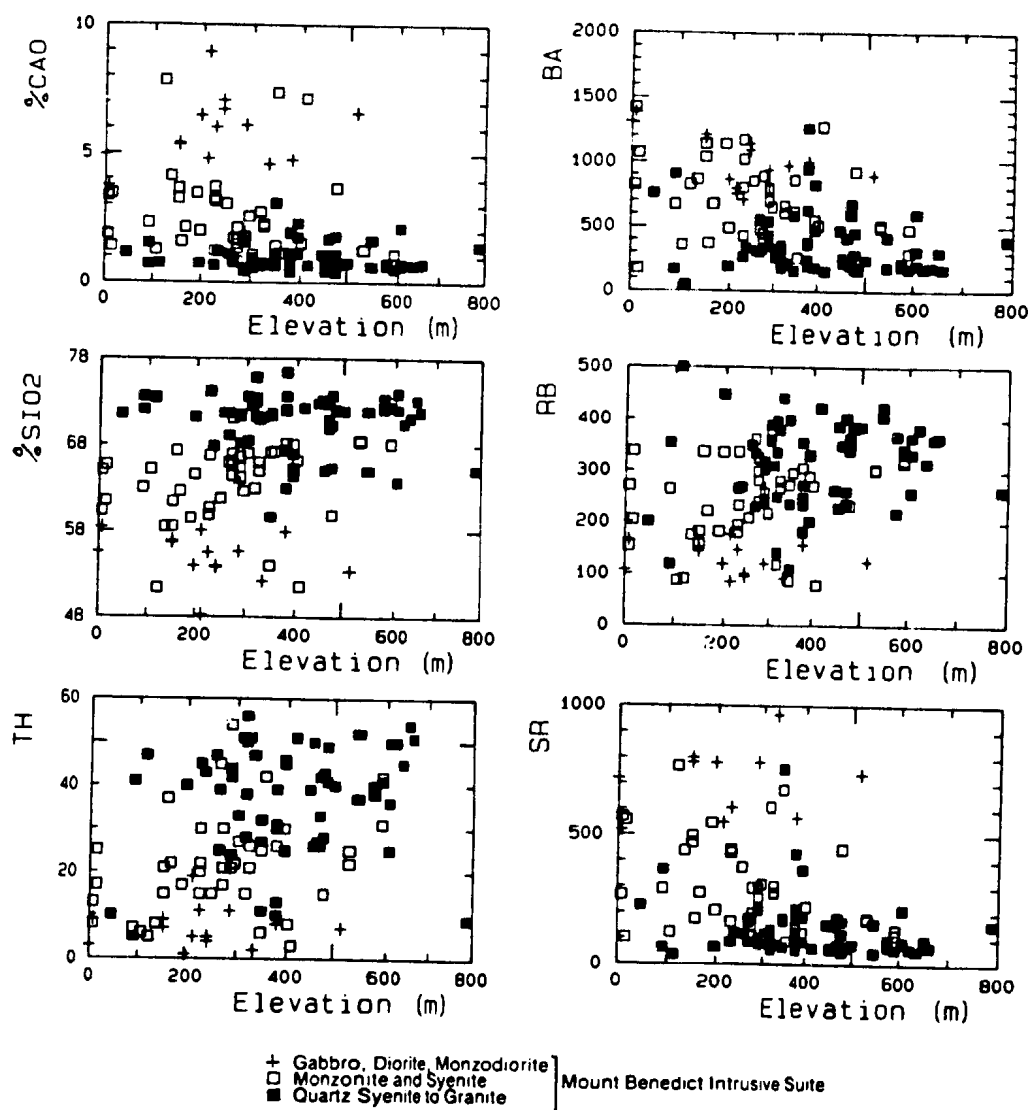
Figure 5.18. Variation of selected major and trace elements against
elevation (metres above sea level) in the Mount Benedict
Intrusive Suite, illustrating the dominance of evolved
compositions at high elevations.
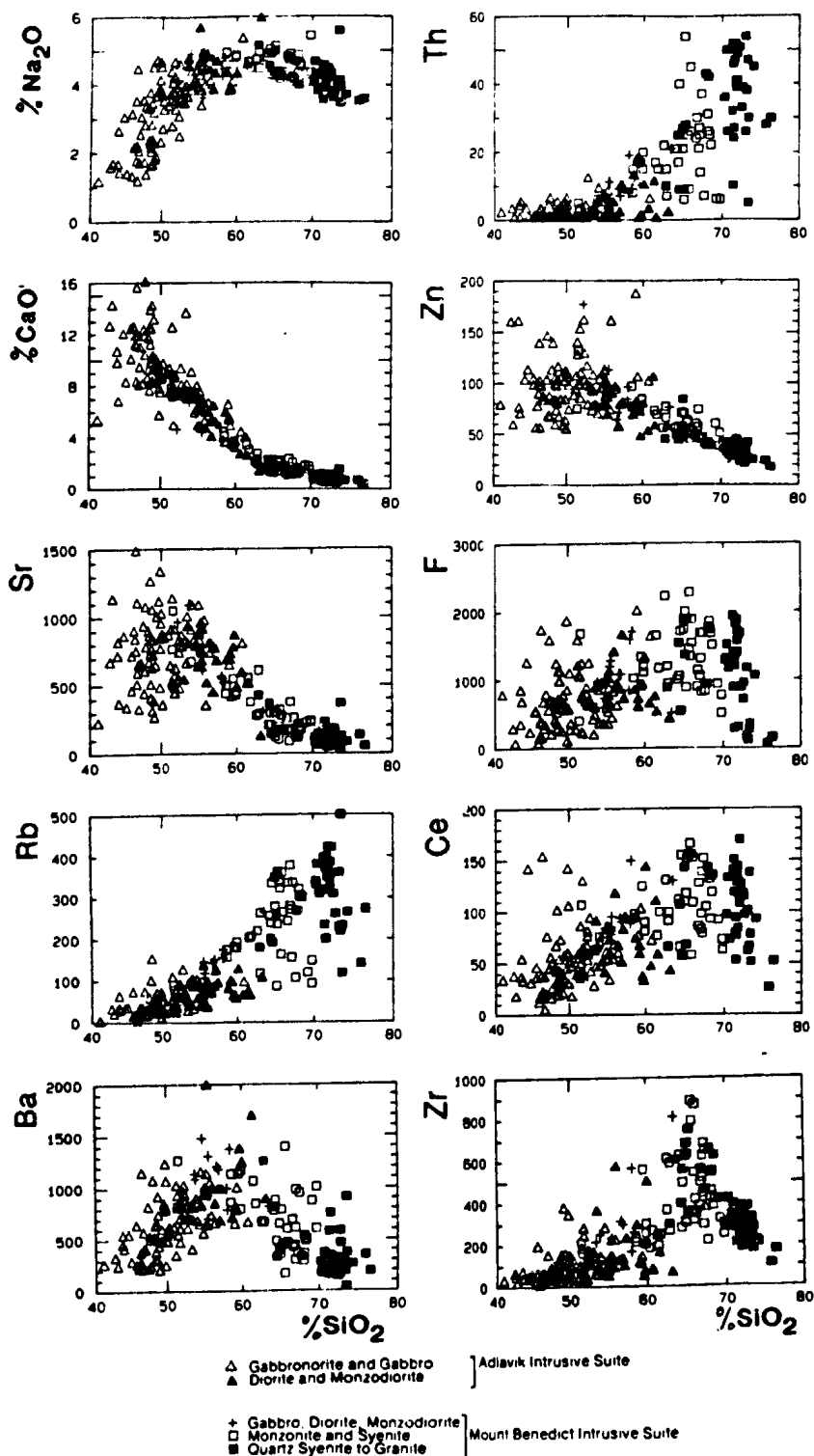
Figure 5.19. Variation of selected major and trace elements against SiO$_2$ in the Adlavik and Mount Benedict Intrusive Suites, illustrating their geochemical continuity.

Mount Benedict Suite is consistent with extended fractionation of a mafic parent magma, for which the most logical candidate is the contemporaneous Adlavik Suite.

Fractional Crystallization Models

The above hypothesis was tested with a numerical crystallization model using Adlavik Suite mafic rocks as a theoretical parent magma for the Mount Benedict Suite.

Mineral/melt partition coefficients (K_D's) used in the model are mostly mean values measured by Villemant et al. (1981) from a compositionally varied volcanic suite of alkali-basalt parentage. K_D's for orthopyroxene and amphibole, and values for V and Y in all minerals, are from a compilation of basalt-related studies by Jenner (1984). A hypothetical composite "accessory" was awarded an arbitrary K_D value of 100 for elements considered to be concentrated in these minerals at various stages. All K_D values employed are listed in Appendix C. The model was constructed for U, Th, La, Y, Rb, Zr, Ba, Sr, V, Cr, Ni and Ti; these elements provide a spectrum of trace element behaviour.

Calculations were performed using the Rayleigh fractionation equation (e.g. Arth, 1976; Hanson, 1978), which assumes perfect instantaneous removal of solid from equilibrium. The term F_L is used below to denote the fraction of liquid remaining at each step. An incremental equilibrium crystallization model (c.f. McCarthy and Hasty, 1976) was also tested, but, unless increments are unrealistically large (> 0.2), differs minimally from the Rayleigh model. Model compositions are represented using spider-type charts normalized to the model parental magma

composition (Figure 5.20b). The observed compositions were summarized by calculation of arithmetic means for 5% SiO_2 intervals, and displayed in the same manner (Figure 5.20a).

Mount Benedict Suite Fractionation Model

Starting Materials : The average composition of Adlavik Suite mafic rocks in the east of the area (Table 3.2, partially listed in Figure 5.20) was taken as a parental magma. The mean major element composition (excluding K_2O; see below) approximates average basalt (from LeMaitre, 1976), suggesting that deviations due to mafic or plagioclase cumulates are cancelled in the mean. Note that for U and Th, poor precision at low levels (Appendix A) causes some uncertainty in the "parent" composition, which is propagated throughout the model.

Description of Model : Stage 1 is dominated by removal of mafic minerals (60% clinopyroxene, 20% orthopyroxene, 10% olivine, 5% oxide and 5% biotite). At $F_L=0.65$, the model corresponds well to the observed composition at ca. 55% SiO_2 (except for Th). It is unlikely that this phase assemblage remained constant, but modest variations in the proportions of Cpx, Opx and Ol do not affect the results significantly. Oxide fractionation is required to deplete V and Cr.

Stage 2 assemblages consist of 55% plagioclase, 25% hornblende, 15% clinopyroxene and 5% biotite. Crystallization until $F_L = 0.26$ creates a model composition that approximates the observed composition at 60-65% SiO_2, corresponding to the dominant monzonite to syenite unit. Key features for this interval are constant Ba, slight Sr depletion, and enrichment in Rb and Zr.
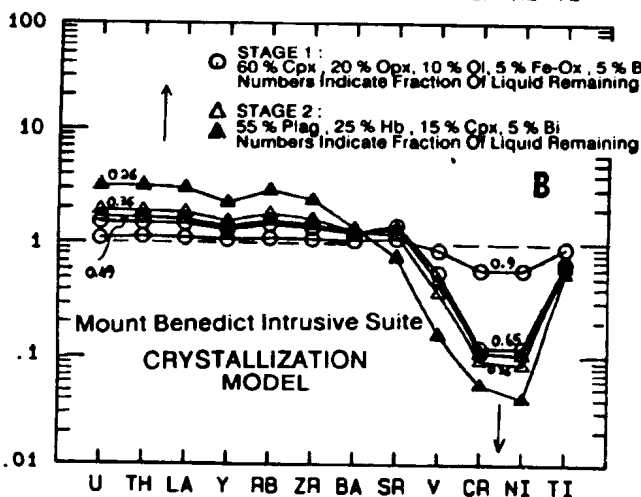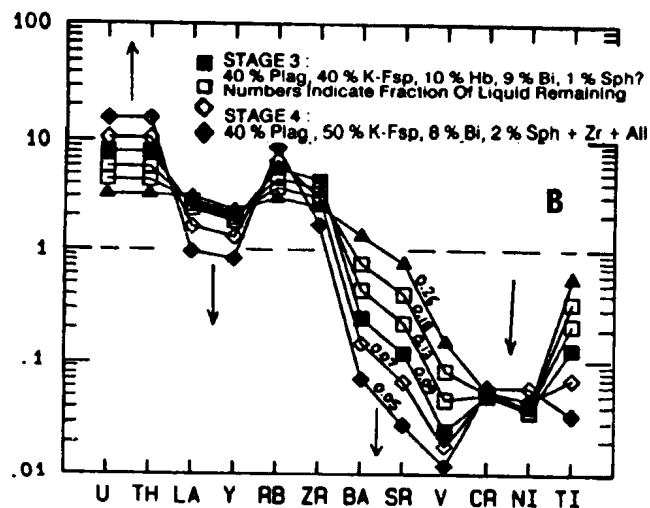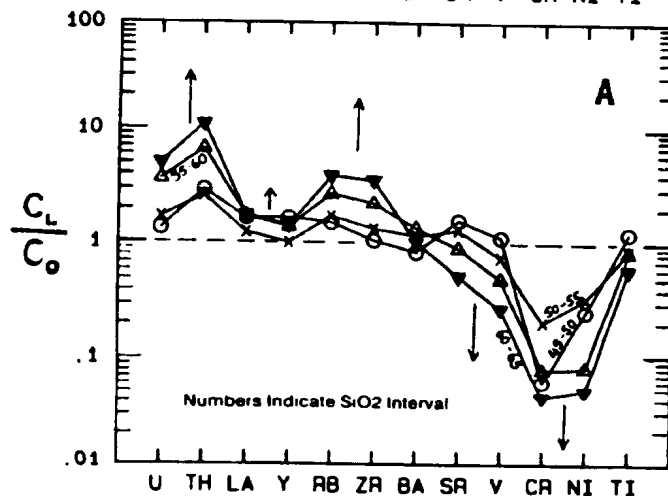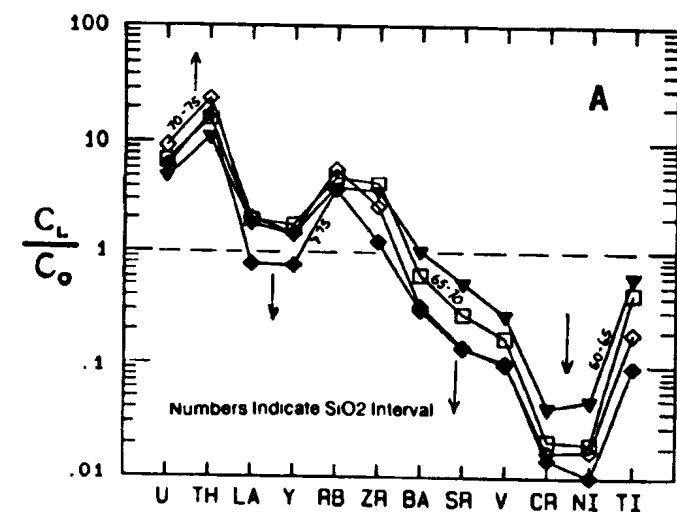
Figure 5.20. Comparison of observed geochemical evolution in the
Mount Benedict Intrusive Suite (A) and the results of a
four-stage fractional crystallization model (B). See text for
details of model and discussion.

Observed Th enrichment is greater than predicted, and La and Y are stabilized at ca. 2 x parent. The former may reflect uncertainties in the U and Th contents of the assumed parent (see above). If the discrepancy between observed and model compositions is real, an alternative explanation is enrichment of U and Th by assimilation of sialic material (see later discussion, also Chapter 8). La and Y behaviour probably reflects the precipitation of sphene, not included in the model up to this point.

Stages 3 and 4 produce the most evolved rocks by crystallization along the plagioclase - K-feldspar cotectic. The liquidus assemblage includes these minerals, plus minor hornblende, biotite and accessory minerals (Figure 5.20). At F_L=0.1, the model fits observed compositions for ca. 70% SiO_2. Buffering of La and Y, and Ti depletion, is maintained by sphene, and zircon crystallization initiates Zr depletion in the most evolved liquids, which correspond to model compositions at F_L=0.05 (except for the persistent Th problem !). The observed Ba and Sr depletion is less than predicted; however, this is easily explained via retention of feldspars in the by now viscous high-silica liquid.

Feasibility of The Model : The model fits the petrographic and geochemical features of both suites, and the proportion of crystallization required appears reasonable. The largest crystallization interval corresponds to the areally dominant complementary association of plagioclase- cumulate leucogabbro and diorite (Adlavik Suite) and plagioclase- porphyritic monzonite and syenite (Mount Benedict Suite). The restricted extent of the most evolved rocks is consistent with a highly fractionated residual magma from a mafic source. The characteristic "speckled-eggshell" texture

probably results from transportation of cumulus plagioclase by convection currents (c.f. Marsh, 1988), which carried them to regions where they were out of equilibrium, and reacted with the liquid or were mantled by K-feldspar. Crystallization at shallow depths along a cotectic phase boundary also allows periodic fluctuations in the liquidus assemblage due to changes in vapour pressure.

Discrepancies for U and Th may, as explained above, be a function of poor estimates for parental compositions. There is, however, independent Nd isotopic evidence for minor crustal assimilation in the Mount Benedict Suite (Chapter 8). Such a process, in combination with crystal fractionation, would further reduce the proportion of crystallization required to generate the most evolved liquids (c.f. DePaolo, 1981a), and thus increases the feasibility of the model.

Affinities Of Labradorian Mafic Magmas and Derivatives

Clark (1973) described the Adlavik Intrusive Suite as a water-rich basaltic magma of "appinitic" affinity. Appinites are small, compositionally varied, mafic to intermediate, subvolcanic, volatile-rich intrusions described from the British Caledonides (e.g. Pitcher and Berger, 1972; Wright and Bowes, 1979; Fowler, 1988). They are characterized by large amphibole crystals; in this respect, the pegmatite facies has an "appinitic" texture. Wright and Bowes (1979) describe rock types and textures from Scotland that are broadly analogous to those described above from the Adlavik Suite. However, such features are not necessarily characteristic, as Mullan and Bussell (1977) report analogous features from hydrous mafic intrusions associated with Mesozoic arc batholiths in Peru and Mexico.

Table 5.5. Comparison of average compositions for the Adlavik Intrusive Suite, Scottish "appinites" (Wright and Bowes,1979; Fowler, 1988), and modern basalt and andesite types (Condie, 1981b).

UNIT	40		41		A1		A2		A3		A4		A5	
n1	117		22		n=19		n=8		n=12		n=4		n=5	
n2	16		5											
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	49.74	4.19	57.64	2.89	48.31	3.66	57.76	1.92	52.41	4.46	49.21	1.80	58.41	3.68
TiO2	0.96	0.43	0.84	0.26	0.97	0.29	0.63	0.12	1.12	0.46	1.32	0.32	0.86	0.34
Al2O3	15.72	3.73	18.10	1.21	12.71	1.74	16.65	1.9	16.02	2.5	12.52	1.03	15.62	1.93
Fe2O3	3.05	1.39	1.99	0.59	2.6	0.98	1.79	0.75	3.43	1.03	7.39	0.72	4.84	1.16
FeO	6.29	1.61	4.17	1.36	6.63	1.18	3.33	1.37	5.89	1.58				
MnO	0.16	0.04	0.12	0.03	0.13	0.03	0.07	0.02	0.15	0.03	0.15	0.01	0.09	0.02
MgO	7.67	4.93	2.36	1.29	11.6	2.46	4.24	2.36	6.16	3.02	7.37	1.14	3.10	1.97
CaO	9.59	2.83	4.95	1.72	8.4	1.79	4.11	1.33	6.66	1.37	9.61	1.22	4.71	2.04
Na2O	3.05	1.15	4.87	0.99	2.44	0.7	3.76	0.61	2.8	1.06	3.49	0.32	4.35	0.93
K2O	1.54	0.89	3.42	0.96	2.13	0.67	4.31	1.56	1.84	0.72	3.72	0.52	5.34	0.61
P2O5	0.34	0.36	0.33	0.14	0.25	0.13	0.26	0.09	0.26	0.17	1.68	0.80	0.64	0.37
LOI	1.42	0.76	0.90	0.51	3.96	0.86	2.51	0.88	3.75	0.98	2.76	1.05	1.55	0.78
TOTAL	99.52		99.67		100.15		99.9		99.89		99.20		99.51	
(ppm) Trace Elements														
Li	22.4	9.2	20.9	6.1	10	5	10	7						
P	732.6	973.4	836.4	316.4										
Sc	32.4	15.7	15.2	5.3	43	16	10	7	26	14				
V	202.6	100.0	91.7	59.5	223	63	227	273	269	163	156.3	22.9	86.8	40.1
Cr	280.0	415.7	24.9	26.5	453	179	83	73	151	140	296.5	45.0	113.4	111.3
Ni	76.5	119.4	10.5	9.5	160	90	49	96	67	110	81.3	36.9	34.8	19.4
Cu	50.6	38.0	22.8	15.6	107	73	82	48	63	60				
Zn	96.5	36.0	76.9	16.3	93	24	66	21	94	17	110.0	15.0	70.4	18.1
Ga	20.2	5.6	18.0	4.8	11	3	14	2	21	3				
Rb	43.0	28.4	81.6	25.5	44	18	131	49	50	33				
Sr	739.7	299.0	667.3	192.4	833	291	1055	433	474	199	2278.5	206.5	2211.2	98.8
Y	19.5	10.0	24.0	9.1	16	4	13	4						
Zr	82.9	70.1	175.6	143.3	87	26	227	96	185	77	341.5	104.1	359.2	73.0
Nb	3.6	4.0	10.4	4.8	8	8	9	5	14	6				
Mo	3.8	3.5	3.4	1.3										
Sn	1.0	0.0	1.2	0.4										
Cs	1.0	1.6	1.4	0.8										
Ba	622.4	406.6	1399.4	1042	899	372	1120	153	480	687	2536.0	644.1	2471.6	420.4
La	23.3	15.3	37.7	10.8	43	24	61	33			190.0	7.2	154.2	12.7
Ce	49.3	31.6	71.3	27.9	37	7	87	218	24	22	416.8	36.2	300.0	39.7
Sm	5.6	2.2	6.5	0.8							21.8	2.4	11.8	2.0
Yb	2.5	0.0	2.5	0.0										
Hf	2.2	2.0	3.2	0.4										
Pb	4.6	6.3	9.5	4.2	15	6	23	9	16	2				
Th	2.0	2.6	5.5	5.5	5	2	9	3	16	24				
U	1.0	0.9	2.2	1.3										

KEY TO ANALYSES:
40 -- Adlavik Intrusive Suite Mafic Rocks (all data)
41 -- Adlavik Intrusive Suite Diorites (all data)
A1 -- "Appinite" Gabbro, Ballachulish Area (Wright and Bowes, 1979)
A2 -- "Appinite" Diorite , Ballachulish Area (Wright and Bowes, 1979)
A3 -- "Appinite", Loch Lomond Area (Wright and Bowes, 1979)
A4 -- "Appinites" with < 52% SiO2, Ach'uaine Area (Fowler,1988)
A5 -- "Appinites" with > 52% SiO2, Ach'uaine Area (Fowler,1988)

n1 -- Number of Analyses for all elements except those listed below
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf

Table 5.5 (continued)

UNIT	NORB	IAB	CAB	CFB	IASB	CASB	IAA	CAA	IASA
n1					n=42	n=21			n=22
n2									
(Wt%)	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
SiO_2	49.80	51.10	50.20	50.30	50.62	51.41	57.30	59.50	55.46
TiO_2	1.50	0.83	1.00	2.20	0.83	0.83	0.58	0.70	0.93
Al_2O_3	16.00	16.10	17.70	14.30	16.01	15.73	17.40	17.20	16.75
Fe_2O_3	2.00	3.00	3.90	3.50	4.11	4.54	2.50	2.50	2.55
FeO	7.50	7.30	6.30	9.30	4.55	3.60	2.70	5.00	4.01
MnO					0.17	0.11			0.10
MgO	7.50	5.10	5.40	5.90	6.24	5.98	3.50	3.40	4.81
CaO	11.20	10.80	9.80	9.70	9.26	6.96	8.70	7.00	6.71
Na_2O	2.80	2.00	2.70	2.50	2.93	3.12	2.60	3.70	2.94
K_2O	0.14	0.30	0.90	0.80	2.74	3.86	0.70	1.60	3.66
P_2O_5					0.44	0.61			0.60
LOI									
TOTAL									
(ppm)									
Li									
P									
Sc					25				26
V					290				218
Cr	300	50	50	100	156		40	55	141
Ni	100	20	50	100	50		15	18	53
Cu	70	80	80	100	159		50	30	115
Zn	75	80	80	90			60	80	
Ga									
Rb	1	5	10	30	59		10	30	63
Sr	135	225	300	350	943		200	385	956
Y	30	20	23	30	16		23	20	18
Zr	100	60	100	200	67		90	110	121
Nb									
Mo									
Sn									
Cs									
Ba	11	60	100	200	683		100	270	567
La	3.5	3.9	9.2	27			3	12	
Ce	12	7	25	140			6.8	25	
Sm	3.9	2.2	3.8	8.2			2.5	3	
Yb	3	2	2.5	2.5			2.7	1.9	
Hf									
Pb									
Th									
U									

KEY TO AVERAGE ANALYSES:
NORB - Mid Ocean Ridge Basalts (compiled by Condie, 1981b)
IAB - Island Arc Basalts (compiled by Condie, 1981b)
CAB - Calc-Alkaline (continental arc) Basalts (compiled by Condie, 1981b)
CFB - Continental Flood Basalts (compiled by Condie, 1981b)
IASB - Island Arc Shoshonitic Basalts (compiled by Morrison, 1980)
CASB - Continental Arc Shoshonitic Basalts (compiled by Morrison, 1980)
IAA - Island Arc Andesites (compiled by Condie, 1981b)
CAA - Calc-Alkaline (continental arc) Andesites (compiled by Condie, 1981b)
IASA - Island Arc Shoshonitic Andesites (compiled by Morrison, 1980)

NOTE : Condie (1981b) does not list sources or numbers of analyses for his compilation.

Table 5.5 lists mean compositions for the Adlavik
Suite, appinites from Scotland (Wright and Bowes,1979;
Fowler, 1988), and average modern basalt and andesite types
(compiled by Condie, 1981b, and Morrison, 1980). The mafic
rocks of the Adlavik Suite are richer in K_2O than all
common modern basalt types, but are less potassic than
shoshonitic basalts. The high Cr, Rb, Sr and Ba content of
the Adlavik Suite, however, corresponds well to
shoshonites. The latter are potassic basalts and andesites
that occur in "mature" (i.e. long-lived or distal to trench
axis) portions of island-arc or continental volcanic arcs
(e.g. Morrison, 1980).

Scottish appinites analyzed by Fowler (1988) have much
greater enrichment in K_2O, Rb, La, Ce, Sr, Ba and Zr than
typical Adlavik Suite gabbro or diorite. There is, however,
a reasonable correspondence to appinites analyzed by Wright
and Bowes (1979), although the Adlavik Suite has lower
K_2O.

Fowler (1988) has proposed that Scottish appinites are
plutonic equivalents of shoshonitic magmas. The Adlavik
Suite is closer in composition to shoshonite than any other
basalt type, and thus probably also represents a
"shoshonitic pluton" in general terms. Morrison (1980)
points out that there is complete gradation between high-K
calc-alkaline volcanic rocks and shoshonites. The Adlavik
Suite is obviously at the other end of the spectrum from
the compositionally extreme appinites of Fowler (1988).

Evolution of Labradorian Siliceous Granitoid Rocks

Labradorian siliceous granitoid units are a
metaluminous to peraluminous association that has low
levels of fluorine, HFS elements and REE. In these

respects, they resemble some of the minor syn-tectonic
Makkovikian granitoids, e.g. the Brumwater and Manak Island
units (Chapter 3), but are distinct from most other
Makkovikian units (Table 5.4).

Monkey Hill Intrusive Suite and Similar Rocks : The
Monkey Hill suite shows great scatter in LFS element
abundances over a narrow range of major element
compositions. Intense depletion of a wide range of elements
is shown by the mineralized Round Pond Granite (Table 5.2,
see also MacDougall, 1988). MacDougall (1988) suggests that
this is a function of hydrothermal alteration associated
with mineralization; the scatter of data for unmineralized
plutons (e.g. the main body) suggests that it may have
affected these to a lesser extent.

Several characteristics of this suite are enigmatic. It
attained fairly high levels in the crust, as demonstrated
by associated tuffisite breccias and mineralized veins.
MacDougall (1988) argued that these magmas were F-enriched,
but that volatiles were mostly lost to hydrothermal fluids
(c.f. Bailey, 1977). The regional geochemistry of the
Monkey Hill Suite suggests that this is unlikely, as
unmineralized plutons show similarly low F contents. Also,
experimental studies indicate that F is preferentially
associated with the silicate magma, and is not strongly
partitioned into fluids (Dingwell, 1988). For example, the
Cape Strawberry Granite (also associated with volatile loss
and mineralization), locally retained up to 5000 ppm
fluorine.

Low REE and HFS element levels in these granites
probably indicate early crystallization of accessory
minerals or presence of such phases in the source regions
of partial melting. Hydrothermal depletion of REE was

suggested by MacDougall (1988) for the Round Pond Granite,
and linked to high REE contents in associated veins.
However, as in the case of fluorine, there is little
evidence of REE enrichment in any Monkey Hill Suite
granites. It is more likely that these granitoid magmas had
low F, HFS element and REE abundances throughout evolution,
and not simply as a consequence of late hydrothermal
activity and mineralization. This suggests in turn
radically different origins from the metaluminous --
peralkaline Makkovikian granitoid magmas.

Otter Lake - Walker Lake Granitoid : This unit lacks
the LFS element scatter evident in the Monkey Hill Suite,
and trace element trends are consistent with removal of
both plagioclase and K-feldspar, as indicated by
phenocrysts of both. Low HFS and REE values may indicate early
stabilization and removal of sphene and/or zircon. However,
interstitial sphene (5.1.5) argues against early removal of
this particular phase. Lack of HFS and REE enrichment in
these rocks may, as outlined above, therefore reflect low
levels of these elements from the outset, as a function of
the source(s) and generative process(es).

CHAPTER SIX
UNCLASSIFIED PLUTONIC ROCKS

Chapter Abstract

Unclassified plutonic rocks comprise four largely undeformed units within the Makkovik Province, and an extensive belt of strongly foliated granitoid gneisses within the Grenville Province, south of the Benedict Fault zone.

The Freshsteak and Noarse Lake Granitoids are lithologically similar, hornblende-biotite quartz monzonite to monzogranite units that probably represent an originally continuous pluton that was disrupted by dextral movements along the Adlavik Brook fault zone. They both show petrographic and geochemical similarities to the syn-tectonic Makkovikian Long Island.Quartz Monzonite.

The Stag Bay Granitoid is a compositionally variable, porphyritic to megacrystic, biotite-hornblende granodiorite to granite unit. In terms of field appearance and petrography, it resembles the Labradorian Otter Lake - Walker Lake Granitoid.

The Jeanette Bay Quartz Syenite and Thunder Mountain Syenite are minor units that show no obvious similarity to other Makkovikian or Labradorian units and, in geochemical terms, could belong to either assemblage. The former was previously grouped with the Mount Benedict Intrusive Suite, but is shows much less incompatible element enrichment.

Granitoid gneisses predominate south of the Benedict Fault system, and probably represent reworked equivalents of TLGB granitoids in the north. The Benedict Fault is a composite zone of intense deformation and mylonitization that dips steeply to the south. The gneisses form a composite unit, representing a range of protolith compositions in variable states of deformation. Locally, they appear to be strongly deformed equivalents of rocks that occur immediately to the north of the fault zone. Fine-grained, variably banded, muscovite-bearing granitoid gneisses that occur south of the fault only are probably strongly mylonitized rock types. The bulk major element compositional spectrum of the gneisses resembles that of the Makkovikian assemblage, but transitional peralkaline compositions are absent.

A Rb-Sr isochron obtained late in this study indicates a Makkovikian age of 1798 ± 48 Ma for the Freshsteak Granitoid. Preliminary (discordant) U-Pb zircon data (Krogh et al., in prep.) suggest that the Stag Bay Granitoid is probably also of Makkovikian age.

Introduction

This association comprises four largely undeformed units within the Makkovik Province, and a large area of granitoid gneisses within the Grenville Province south of the Benedict Fault zone. In the case of one unit (Freshsteak Granitoid), Rb-Sr isotopic data acquired late in thesis preparation indicate a Makkovikian age of ca. 1800 Ma. Locations and boundaries of unclassified units are indicated in Figure 6.1. Key field and petrographic features of these units are summarized in Table 6.1.

6.1 GEOLOGY and PETROLOGY

6.1.1 Freshsteak and Noarse Lake Granitoids

These two units are closely similar in lithology, and are interpreted to be portions of an originally continous pluton, that has been displaced dextrally by the Adlavik Brook fault zone (Figure 6.1). The northern area (Freshsteak Granitoid) is a new subdivision of unit 27 (undivided granitoid rocks) of Gower et al.(1982). The southern area (Noarse Lake Granitoid) is broadly equivalent to Unit 13 of Bailey (1979), grouped also by Gower et al.(1982) in their unit 27. Both areas are dominated by brown to grey medium-grained, plagioclase porphyritic, melanocratic quartz monzonite, granodiorite and monzogranite (Table 6.1; Plate 6.1).

The full areal extent of the Noarse Lake Granitoid is unclear, as a large area to its east is obscured by glacial drift. Matching plutonic units and the Upper Aillik Group

59°00'W

55°30'N

0 Km 25

N

Archean Gneiss Complex

Aillik Group (undivided)

QUEBEC

LABRADOR

200 km

Turnavik Islands

Bay of Islands

Ironbound Islands

Adlavik Islands

Ragged Islands

Cape Harrison

Big Bight

Kaipokok Bay

Adlavik Bay

Adlavik Brook

Fault Zone

Tukialik Bay

Jeanette Bay

Benedict Fault Zone

L. Michael

KEY TO UNITS (Map Number in Parentheses)

Freshsteak Granitoid (1)
Noarse Lake Granitoid (2)

Stag Bay Granitoid (3)

Thunder Mountain Syenite (4)

Jeanette Bay Quartz Syenite (5)

Granitoid Gneisses South of
Benedict Fault Zone   (6)

Fault Zone

Figure 6.1. Summary map illustrating the distribution and extent of
unclassified plutonic units.

Table 6.1. Key features of unclassified plutonic units.

Map Unit	Suite/Unit/Age	General Characteristics	Textural Characteristics
60.0	Freshsteak Granitoid 1798 +/- 48 Ma [Rb-Sr WR] (this study)	Grey to green or brown, variably Plag-porphyritic, melanocratic quartz monzonite, granodiorite and monzogranite. Generally massive but slightly recrystallized, and locally foliated.	Generally medium-grained, with small, equant Plag phenocrysts up to 1 cm diameter. Locally K-feldspar porphyritic. Local foliations are defined by alignment of mafic silicates. Interstitial quartz in
61.0	Noarse Lake Granitoid	Similar to the least deformed variants of Long Island Quartz Monzonite.	massive variants. Interstitial Quartz - K-feldspar graphic intergrowths in places.
62.0	Stag Bay Granitoid 1712 +/- 24 Ma [Rb-Sr WR] (this study)	Grey to pink or buff, porphyritic to seriate granodiorite, monzogranite, granite and local alkali-feldspar granite. Northern part of unit is generally massive; locally foliated or sheared in the south.	Generally medium to coarse grained, commonly with phenocrysts of both Plag and K-fsp; K-fsp phenocrysts up to 5 cm diameter. Texture locally seriate or megacrystic. Groundmass equigranular to seriate. Cataclastic variants in the south are locally augen-textured.
63.0	Jeanette Bay Quartz Syenite	Pink to grey, variably K-fsp porphyritic, homogeneous quartz syenite and granite. Generally massive, but locally has sheared appearance.	Generally coarse-grained, with phenocrysts of K-fsp and Plag in most samples (K-fsp > Plag). Locally shows pseudorapakivi textures, rarely true rapakivi textures.
64.0	Thunder Mountain Syenite	Grey to buff or pink, K-feldspar porphyritic, monzonite, syenite, quartz syenite to local granite. Commonly shows interstitial blue quartz. Very fresh and massive.	Coarse to very coarse grained, with large (up to 5 cm) K-fsp phenocrysts. Smaller Plag phenocrysts occur locally. Slightly recrystallized, but not foliated.
66.0	Granitoid Gneisses South of the Benedict Fault Zone	Highly variable assemblage of foliated granitoid rocks, granitoid gneisses, and banded, mylonitic rocks. The most common rock types are augen gneisses with cataclastic textures, probably derivatives of K-fsp porphyritic or megacrystic granites.	Commonly medium to coarse grained, strongly foliated rocks. K-fsp and lesser Plag augen form deformed phenocrysts; relict pseudorapakivi textures occur locally in area south of Big River Granite. Fine-grained, banded variants have grey and pink layers, but do not appear migmatized.

Table 6.1 (continued).

Key Field Relationships	Mineralogy	Petrography
Contact relations with surrounding units unknown. Presumed to intrude adjacent foliated syn-tectonic Makkovikian granitoids. Unit is disrupted by Adlavik Brook Fault zone. Freshsteak and Moarse Lake bodies are probably displaced portions of a single pluton.	Quartz (10-30%, generally < 20%) K-fsp (Mi, perthitic, 30-50%) Plag (An25-40; 30-50%) Hb + Bi (5-20% total, subequal) Cpx (relict) Accessory Sph, Ap, lesser Zr, All	Igneous textures generally well-preserved. Plag phenocrysts zoned and have saussuritized cores with clear sodic rims. Graphic Qz - K-fsp intergrowths occur locally, Qz is commonly interstitial. Relict Cpx rimmed by Hb. Hb locally poikilitic.
Contact relations mostly unknown. Northern part of unit is cut by Feldspar-porphyry dyke that resembles the Dog Island Granite. Southern part of unit is cut by several faults and mylonitic zones.	Quartz (15-35%) K-fsp (Mi, 25-65%) Plag (saussuritized, 15-50%) Hb (0-5%) Bi (green, 5-10%) Accessory Sph, Ap, Zr, All Ep + Chl in foliated variants	Quartz variably strained, locally interstitial. Plag phenocrysts are subhedral, strongly saussuritized and commonly zoned. Mi is coarse patch perthite. Bi (+/- Hb) forms aggregates or clots, with variable Sph + Ep.
Contact relationships unknown. Previously considered to be related to syenites of Mount Benedict Suite, which adjoin it. However, geochemical data suggests that it is distinct.	Quartz (10-20%) K-Fsp (Mi, 50-70%) Plag (10-30%) Hb + Bi (5-15%, subequal) Cpx (relict) Accessory Sph, All, Zr Ep + Chl (secondary)	Cores of Plag phenocrysts are saussuritized, locally zoned. Groundmass consists of Plag + K-fsp + Qz. In many samples, mafic minerals are altered to Ep + Chl.
Northern and southern contacts are inferred fault zones, other contact relations unknown.	Quartz (interstitial, 10-20%) K-fsp (Mi, 50-75%) Plag (> An30, 5-30%) Hb + Bi (5-12% total, Hb > Bi) Cpx (relict) Accessory Sph, Ap, Zr.	Quartz slightly recrystallized. Mi phenocrysts have relict simple twinning, originally orthoclase? Cpx is locally green, resembles Ae-augite, but unit is not peralkaline.
Northern boundary is Benedict Fault zone, a 1 km wide zone of intense deformation, local mylonitization. Several East-trending structures in the granitoid gneisses are defined by mylonitic zones. Fine-grained, banded gneisses are interpreted as mylonitized granitoids.	Generally leucocratic, with 80-95% total Qz + Fsps. Mineral proportions variable; most are K-fsp rich siliceous granitoids, but syenitic gneisses occur locally. Most common mafic minerals are green Hb and brown Bi, present as fine-grained aggregates defining foliations. Cpx very rare, Chl +/- Ms present locally. Gnt very rare.	Very strong recrystallization, with Qz + Fsps forming polygonal or (more commonly) blastomylonitic to ribboned aggregates. Augen locally preserve perthitic texture, but commonly polygonal aggregates. Microcrystalline mylonitic zones parallel to foliation, and wrapping around Fsp augen.

after removal of dextral displacement along the Adlavik
Brook fault zone suggests that the Noarse Lake granitoid
may underly much of this unexposed zone. Contact
relationships of both units are unknown. A Rb-Sr isochron
from the Freshsteak Granitoid indicates an age of 1798 ± 48
Ma (Chapter 8), suggesting that this is a Makkovikian
intrusion of probable post-tectonic affinity [*].

Both units are predominantly medium-grained and
melanocratic, and contain small plagioclase phenocrysts (up
to 1 cm diameter), commonly with zoned and/or saussuritized
cores. Groundmass quartz and feldspar is variably
recrystallized, but graphic quartz/K-feldspar intergrowths
or angular interstitial quartz grains are preserved in many
areas. Slight foliations, of variable orientation, are
present close to the trace of the Adlavik Brook fault zone;
the Noarse Lake body shows generally more intense
recrystallization than the Freshsteak Granitoid.

Field appearance and petrographic characteristics of
these units are similar to massive and weakly deformed
examples of the Long Island Quartz Monzonite. The Rb-Sr age
obtained for the Freshsteak unit (Chapter 8) is similar to
K-Ar and U-Pb ages from the Long Island unit (Gandhi et
al., 1969; 1988).

6.1.2 Stag Bay Granitoid

This unit corresponds to Unit 19 of Gower (1981), and
to a portion of Unit 26 of Gower et al. (1982). Gower
(1981) grouped the unit with megacrystic granodiorite

---

[*] NOTE : *Preliminary Rb-Sr data were inconclusive, and
additional data did not become available until after text
and illustrations for Chapter 4 were finalized. The
descriptive material on this unit has thus been retained in
this chapter.*

- 242 -
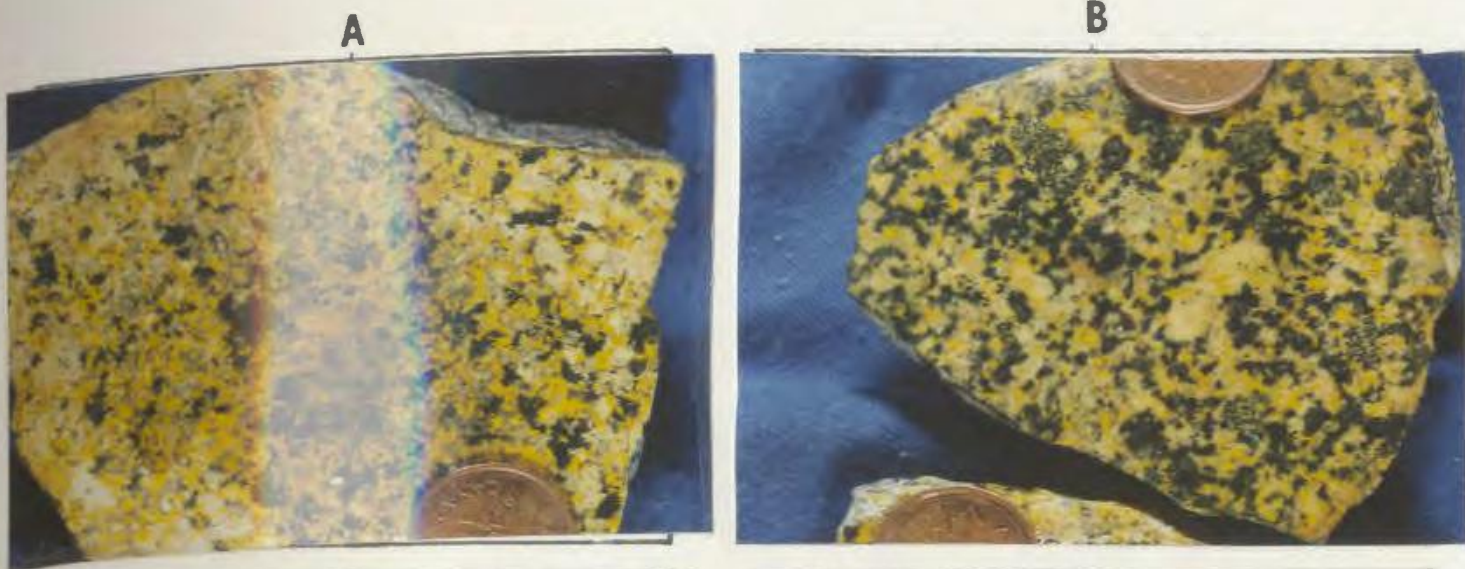
Plate 6.1. Features of the Freshsteak and Noarse Lake Granitoids. (a) Freshsteak Granitoid. (b) Noarse Lake Granitoid. Note that these units are locally more foliated and recrystallized than these slabs. Slabs stained for K-feldspar.

Plate 6.2. Features of the Stag Bay Granitoid. (a) and (b) Typical porphyritic granodiorite to monzogranite, Stag Bay. Note weak foliation in (b). Note that this unit is variable in composition and texture. Slabs stained for K-feldspar.

exposed near Deus Cape, and with similar megacrystic granitoids east of the study area. The unit includes a variety of rock types, the most abundant of which is a seriate to two-feldspar porphyritic granodiorite, monzogranite or granite (Table 6.1; Plate 6.2; see also description of Gower, 1981).

Contact relationships of the unit are unknown. At Stag Bay, it is cut by a feldspar-porphyry dyke which may be related to the nearby Dog Islands Granite, but might also be associated with nearby subvolcanic porphyry units assigned to the Upper Aillik Group (Jagged Edge assembalge; Chapter 7). Rb-Sr data (5 point only) yielded an ambiguous 1714 ± 44 Ma isochron (Chapter 8). U-Pb zircon dating is in progress.[*].

K-feldspar and plagioclase are commonly both present as phenocryst phases; the former are generally larger, ranging up to 5 cm in size. In the north the unit is generally massive, but the southern part is locally foliated and/or cataclastic in texture. This area is cut by several faults that link the Adlavik Brook and Benedict fault zones, and foliation directions are highly variable. Gower (1981) indicates N-trending foliations in two areas near the coast that were not visited during this study. Of the units described in preceding chapters, this unit shows the closest resemblance to the Otter Lake - Walker Lake Granitoid, which is also two-feldspar porphyritic in most areas. The distance between the units suggests, however, that a direct connection is unlikely.

* NOTE : *Preliminary U-Pb zircon data (Krogh et al., in prep.) are slightly discordant, but appear colinear with other post-tectonic Makkovikian units, and indicate a similar age of 1790 - 1805 Ma. The Stag Bay unit is therefore.almost certainly a Makkovikian intrusion.*

6.1.3 Jeanette Bay Quartz Syenite

This small body is located in the Benedict Mountains south of Jeanette Bay. It corresponds to unit 22 of Gower (1981), and was considered by him to be related to the rocks here termed Mount Benedict Intrusive Suite (unit 21 of Gower,1981). However, it mostly lacks the distinctive textural characteristics of these rocks, and is geochemically distinct (see 6.2). It is dominated by pink to grey, coarse-grained, variably K-feldspar porphyritic quartz syenite to granite (Table 6.1; Plate 6.3). Contact relationships are unknown. It is commonly massive, but locally appears slightly foliated and/or sheared. Microcline is the most common phenocryst phase. Plagioclase cores in sporadic pseudorapakivi phenocrysts are commonly zoned and saussuritized. In many samples, the mafic mineral assemblage has been retrogressed to chlorite - epidote - sphene aggregates. The groundmass is plagioclase-rich compared to the K-feldspar and quartz groundmass typical of the adjacent Mount Benedict Suite, a contrast previously noted by Gower (1981). In general, it appears more recrystallized than the normally pristine rocks of the Mount Benedict Intrusive Suite.

6.1.4 Thunder Mountain Syenite

This small body occurs southwest of Stag Bay, between the Benedict fault system and another northwest-trending fault mapped by Gower (1981). It is equivalent to a portion of unit 26 of Gower et al. (1982). It consists mostly of coarse grained, massive, K-feldspar porphyritic, hornblende monzonite, syenite, quartz syenite and granite (Table 6.1; Plate 6.4). It is in (inferred) fault contact
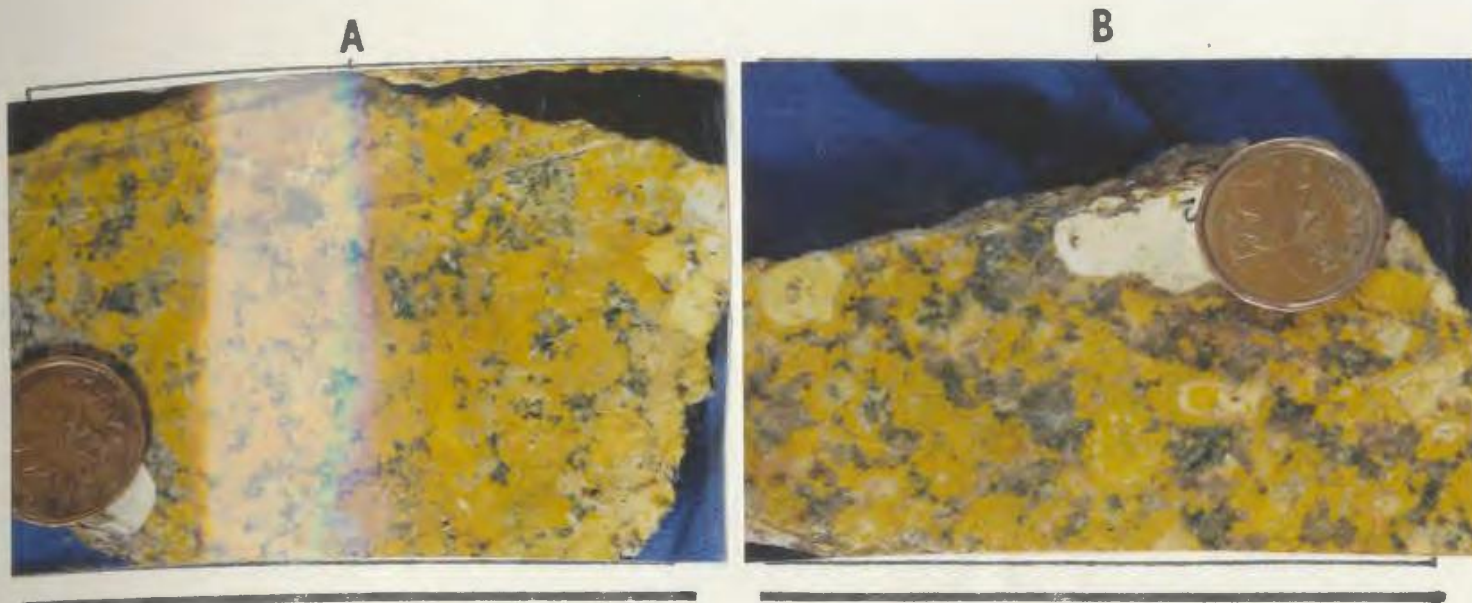
Plate 6.3. Features of the Jeanette Bay Quartz Syenite. (a) and (b) Typical examples. Slabs stained for K-feldspar.
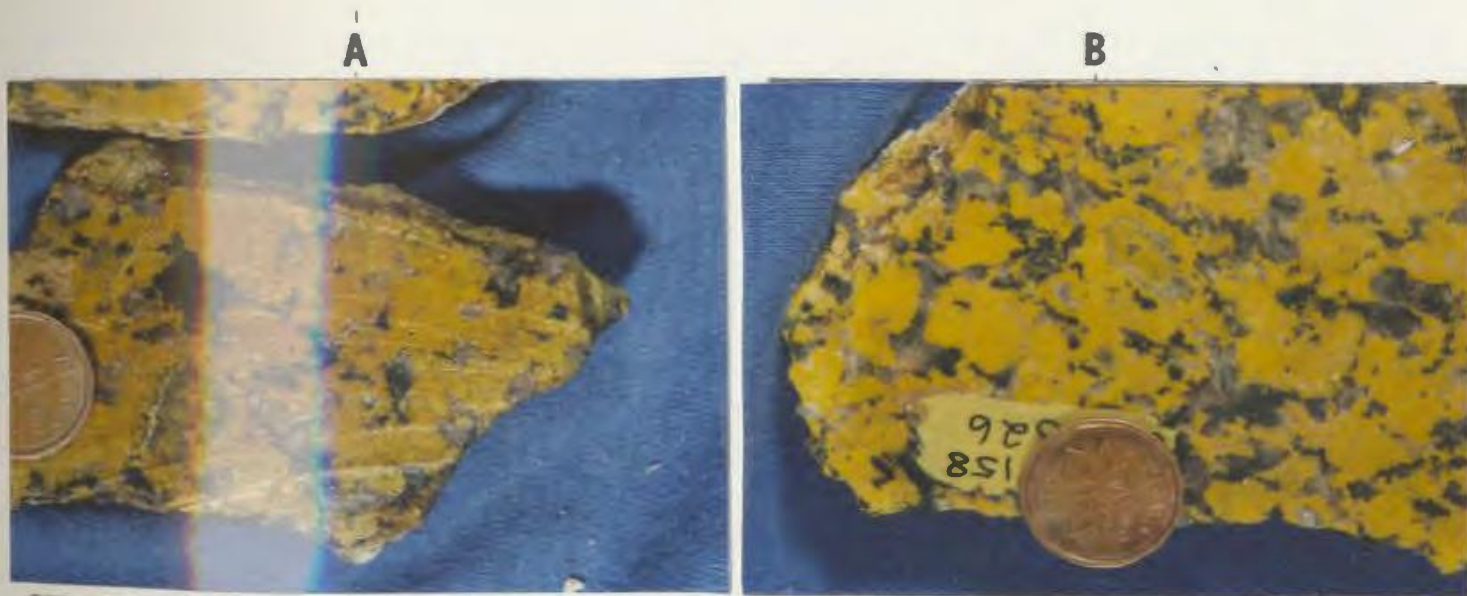
Plate 6.4. Features of the Thunder Mountain Syenite. (a) and (b) Typical examples. Slabs stained for K-feldspar.

with the Stag Bay Granitoid and part of the Mount Benedict
Intrusive Suite to the north, and with granitoid gneisses
of the Grenville Province to the south. Eastern and western
contact relations are unknown. In most areas, it is massive
and undeformed, and is characterized by distinctive
interstitial blue quartz grains. Large (up to 5 cm
diameter) microcline phenocrysts have both simple and
polysynthetic twinning, possibly indicating original
orthoclase phenocrysts. Zoned plagioclase phenocrysts are
locally present. Green clinopyroxene is a local relict
phase, and is altered to hornblende and a red-brown phase.
The pyroxene resembles aegirine-augite, but is generally
non-pleochroic.

6.1.5 Granitoid Gneisses South Of The Benedict Fault Zone

General Characteristics : South of the Benedict fault
zone (Figure 6.1), all units exhibit moderate to intense
east-trending foliations attributed to Grenvillian
deformation, and many are gneissic or banded in texture.
These rocks have not been studied in detail in this
project, and are thus grouped as a single map unit. This
composite unit clearly consists of a variety of rock types
in highly variable states of deformation. All areas south
of the Benedict Fault zone are poorly exposed (excluding
river courses), and the most prominent outcrops are
invariably Michael Gabbro intrusions. Characteristics and
relationships of different granitoid gneiss variants in
this part of the Grenville Province are thus poorly known.

Field Relations and Lithology : The northern boundary
of the gneissic terrane is the Benedict Fault zone itself,
although some areas north of the generally accepted
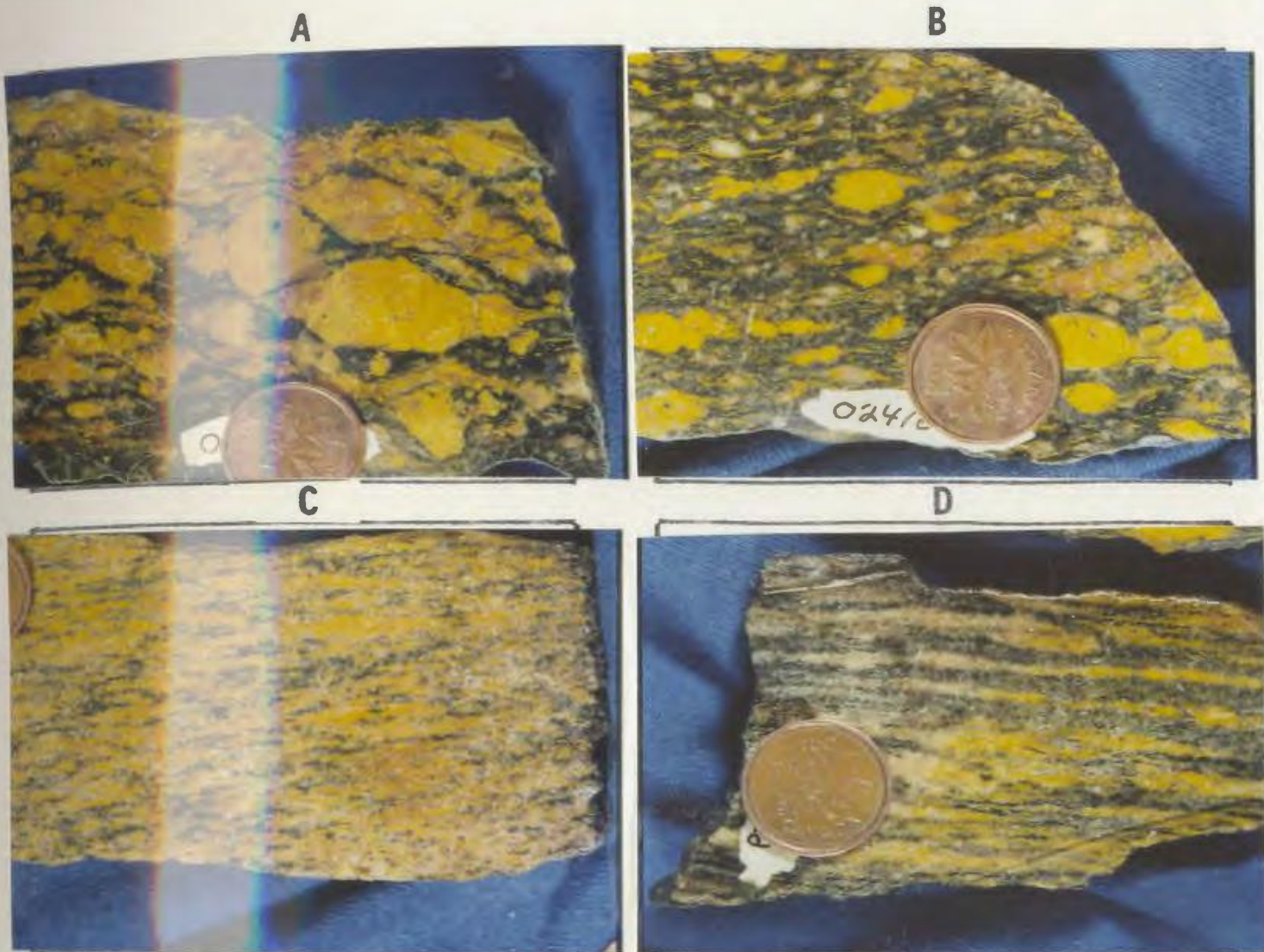
Plate 6.5. Features of the granitoid gneisses exposed south of the Benedict fault zone. (a) to (d) Typical examples, showing development of augen textures, and banded, mylonitic appearance resulting from ultradeformation. Slabs stained for K-feldspar.

position of this fault exhibit deformation of equivalent
intensity, and are included in the gneiss unit (Figure
6.1). The Benedict fault is a composite zone that cannot be
represented adequately by a single line on a map. In the
west of the study area, it is described by Bailey (1979) as
a broad zone of mylonitization displaying a subvertical
lineation. The zone is well exposed in Big River, where it
is a composite feature consisting of a broad zone of
intense deformation (up to 1 km in width) within which
occur a number of individual mylonite zones, dipping at
$40-70^{\circ}$ S, with steeply plunging lineations upon foliation
surfaces. In the Benedict Mountains, Gower (1981) described
it as a south-dipping reverse fault displaying evidence
also of dextral motion. The contrast in deformation state
across the fault is extreme in this area, and it appears to
be a narrower, more tightly focussed structure than in the
west (see below).

South of the main fault zone, a number of discontinous
cataclastic and mylonitic zones occur within the granitoid
gneisses. Fine-grained, strongly foliated granitoid
gneisses form concordant layers within coarser foliated
granitoids; these may be original textural variants, but
more likely represent mylonitic zones developed on a
hand-sample or outcrop scale. On a regional scale, these
are interpreted to have an anas'.omosing pattern, similar to
that seen in many hand specimens that have relict
porphyritic textures (Plate 6.5).

The granitoid gneisses appear (at least locally) to
resemble adjacent rock types north of the Benedict Fault
zone. For example, in the area south of the Big Riv;1
Granite, they comprise pink or buff, coarse grained,
cataclastic to mylonitic, augen-textured rocks that have a
composition approximating biotite-hornblende granite or

alkali-feldspar granite. Vestiges of pseudorapakivi texture
are present in the least deformed examples, and they
contain blue-green hornblende typical of the Big River
Granite. A similar relationship was noted by Gower (1981)
in the eastern Benedict Mountains, where megacrystic
granitoids and augen gneisses occur north and south of the
fault respectively. South of the main Benedict Mountains
massif, the contrast in deformation state across the fault
is extreme, and occurs principally across faults that
bound a narrow metavolcanic enclave (Figure 6.2). The rocks
south of the fault zone in this area comprise a
heterogeneous mixture of two contrasting rock types.
Coarse-grained biotite-hornblende augen granitoids display
relict K-feldspar porphyritic textures, and
characteristically contain blue-green hornblende. The mafic
assemblage is variably retrogressed to sphene and epidote.
These rocks are interspersed with fine to medium grained,
equigranular to locally banded, leucocratic, granitoid
gneisses containing minor biotite and muscovite. These two
variants do not neccessarily represent discrete rock types;
Gower (1981) suggests that they may represent variable
deformation and metamorphism of a common protolith,
although the presence of muscovite implies some
compositional contrasts. Gower (1981) distinguished a
strongly deformed augen gneiss of monzonitic to syenitic
composition close to the fault zone, and also two areas of
supracrustal rocks, which he considered to be of
volcaniclastic origin.

6.2 DESCRIPTIVE GEOCHEMISTRY

Unclassified plutonic rocks are represented by 221 samples, of which 211 are regional samples collected on a 2km grid spacing. Over 60% of this population represents the granitoid gneiss unit.

6.2.1 General Geochemistry

Summary of Numerical Data

Table 6.2 lists mean compositions of unclassified plutonic units, and also mean compositions of selected Makkovikian and Labradorian plutonic units that have similar SiO_2 contents.

Mean compositions of the Freshsteak and Noarse Lake units are similar, supporting their interpretation as disrupted components of an originally continous pluton. However, the Noarse Lake unit has a lower mean silica content, and a slightly less evolved trace element pattern. Both units are similar in composition to the Long Island Quartz Monzonite. The Thunder Mountain Syenite has a similar SiO_2 content to these rocks, but is poorer in TiO_2 and P_2O_5.

The Stag Bay and Jeanette Bay units have similar SiO_2 contents (ca. 68%), but are otherwise dissimilar. The latter is richer in K_2O and Rb, and depleted in Sr relative to Stag Bay. However, the Jeanette Bay unit has lower levels of Rb, U, and Th than rocks of comparable SiO_2 content in the Mount Benedict Intrusive Suite. Note

Table 6.2 . Average compositions of unclassified plutonic rocks, subdivided by principal units, and Makkovikian and Labradorian units of similar SiO_2 content.

UNIT	60		61		62		63		64		66	
n1	17		10		21		12		13		146	
n2	4		1		1		0		0		0	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	63.66	5.47	60.44	4.30	68.31	4.68	67.93	4.62	64.37	8.04	68.75	5.54
TiO2	0.87	0.39	1.05	0.35	0.36	0.12	0.47	0.19	0.55	0.29	0.48	0.35
Al2O3	15.48	1.57	16.28	0.67	15.52	1.47	14.99	1.58	16.44	2.21	14.57	1.61
Fe2O3	2.26	0.67	2.12	0.74	1.19	0.83	1.31	0.62	1.41	0.71	1.21	0.63
FeO	3.34	1.33	4.46	1.54	1.52	0.69	1.48	0.71	2.51	1.72	2.03	1.38
MnO	0.12	0.04	0.14	0.04	0.06	0.02	0.06	0.02	0.09	0.05	0.07	0.04
MgO	1.37	0.91	1.88	0.99	0.77	0.52	0.64	0.33	1.86	3.16	0.72	0.70
CaO	3.19	1.62	3.98	1.43	2.20	1.40	1.79	0.96	3.14	2.89	1.81	1.20
Na2O	4.29	0.41	4.44	0.34	4.51	0.43	4.18	0.42	4.49	0.95	4.14	0.50
K2O	4.19	1.08	3.88	1.16	4.17	0.93	5.35	0.83	4.14	1.76	4.85	0.98
P2O5	0.30	0.20	0.32	0.10	0.12	0.08	0.12	0.06	0.15	0.09	0.15	0.14
LOI	0.58	0.26	0.53	0.28	0.80	0.32	1.00	0.55	0.46	0.17	0.55	0.20
TOTAL	99.65		99.52		99.53		99.32		99.61		99.33	
(ppm)	Trace Elements											
Li	21.6	8.5	56.7	44.5	18.2	4.3	15.0	3.8	14.4	4.2	19.8	9.4
F	728.3	258.0	999.1	671.9	741.2	612.2	700.5	349.7	703.8	591.2	649.7	413.7
Sc	9.0	4.7	3.9		2.6							
V	66.9	47.0	93.2	52.6	28.3	26.8	32.7	11.5	42.9	47.8	31.2	27.4
Cr	6.9	6.7	10.1	6.6	4.1	2.4	7.5	3.5	30.3	74.6	9.2	29.6
Ni	2.5	2.5	4.1	2.3	2.4	1.7	2.3	2.2	13.6	32.2	2.7	7.5
Cu	11.7	7.2	10.8	5.0	45.9	175.0	13.3	11.3	8.9	10.1	12.9	54.5
Zn	102.9	27.5	102.8	34.6	49.3	17.2	59.8	32.0	70.3	26.8	66.2	36.7
Ga	21.5	3.1	21.9	3.6	14.1	5.6	9.5	3.4	12.9	6.9	12.3	5.8
Rb	109.1	36.7	118.3	61.8	104.7	44.8	162.9	50.6	69.5	55.7	112.6	44.7
Sr	359.9	184.7	410.4	138.2	474.5	267.3	232.8	129.0	462.0	326.8	253.4	188.7
Y	49.6	22.0	35.4	6.9	24.6	19.5	31.5	9.5	22.9	16.1	32.1	14.9
Zr	307.1	156.4	221.9	103.8	254.4	149.6	322.0	126.8	340.3	455.6	338.6	162.0
Nb	16.4	7.3	10.7	3.6	12.9	9.7	15.9	5.2	11.7	10.8	15.3	7.1
Mo	4.2	1.2	4.4	1.6	3.0	1.9	5.3	5.7	3.3	1.0	3.8	2.1
Sn	2.3	1.5	1.0		2.0							
Cs	1.9	1.0	5.0		2.0							
Ba	1368.4	545.3	1906.0	685.8	987.8	406.4	819.0	189.7	1512.1	1628	907.3	637.2
La	68.5	29.4	43.5	8.0	44.9	35.8	48.6	22.5	36.2	28.6	43.8	27.4
Ce	128.4	58.8	82.9	15.4	90.1	74.8	93.6	38.7	74.9	62.2	89.6	52.4
Sm	14.0	4.1	4.3		4.6							
Yb	4.8	2.7	2.5		2 5							
Hf	11.5	3.4	5.0		13.0							
Pb	15.3	3.6	13.8	4.7	17.3	19.8	23.8	9.7	12.2	8.0	18.6	42.4
Th	5.0	5.9	2.9	2.6	10.4	17.1	13.3	7.9	4.5	8.5	7.8	7.8
U	3.2	1.6	2.8	1.0	4.3	3.4	4.0	1.1	1.5	1.9	3.6	2.6
(Wt%)	Partial CIPW norm											
Q	14.00	8.06	8.04	6.31	19.44	8.14	19.24	9.00	13.37	11.05	20.55	10.35
C	0.00	0.00	0.00	0.00	0.21	0.26	0.03	0.06	0.10	0.20	0.08	0.16
Or	24.96	6.38	23.13	6.89	24.95	5.55	32.18	5.19	24.65	10.43	28.97	5.84
Ab	36.58	3.45	37.94	2.90	38.61	3.78	35.07	2.52	38.22	8.01	35.53	4.22
An	10.74	5.53	13.16	3.92	9.36	4.97	6.35	3.53	12.33	11.13	6.72	4.24
Di	3.04	1.64	4.28	2.44	1.02	2.17	1.50	1.73	2.32	3.10	1.41	1.62
Hy	5.03	3.06	7.62	2.80	2.58	1.28	1.90	1.44	3.56	2.13	3.21	2.76
Ol	0.00	0.00	0.00	0.00	0.15	0.70	0.00	0.00	1.95	4.96	0.02	0.19
Mt	3.31	1.00	3.11	1.07	1.75	1.20	1.89	0.87	2.07	1.05	1.76	0.93
Il	1.66	0.75	2.01	0.66	0.69	0.24	0.91	0.36	1.06	0.55	0.94	0.67

KEY TO UNITS:
60 -- Freshsteak Granitoid   63 -- Jeanette Bay quartz syenite
61 -- Noarse Lake Granitoid   64 -- Thunder Mountain Syenite
62 -- Stag Bay Granitoid   66 -- Granitoid Gneisses south of Benedict Fault

n1 -- Number of analyses for all elements except those listed below
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf

Table 6.2 (continued).

UNIT	10		20		43		44		48		30	
n1	15		57		53		6?		49		79	
n2	5		12		22		39		11		13	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO_2	63.32	1.27	62.31	4.27	64.46	4.46	70.69	3.31	68.54	4.42	70.11	5.15
TiO_2	0.88	0.06	0.78	0.29	0.61	0.24	0.30	0.18	0.44	0.20	0.39	0.22
Al_2O_3	15.81	0.24	16.69	1.49	16.03	0.93	14.39	1.06	14.98	1.62	14.43	1.74
Fe_2O_3	1.79	0.37	1.72	0.75	1.40	0.66	0.97	0.40	1.20	0.61	1.16	0.55
FeO	3.06	0.73	3.41	1.12	2.53	1.12	1.09	0.66	1.87	1.01	1.49	0.97
MnO	0.10	0.01	0.12	0.05	0.09	0.03	0.05	0.02	0.06	0.03	0.06	0.04
MgO	1.25	0.42	1.22	0.87	1.12	0.97	0.38	0.27	0.86	0.54	0.50	0.84
CaO	2.95	0.48	2.92	1.30	2.37	1.52	0.97	0.49	2.04	1.02	1.36	1.20
Na_2O	4.27	0.25	4.57	0.41	4.51	0.36	4.28	0.43	3.89	0.55	4.28	0.75
K_2O	4.75	0.49	5.14	1.09	5.41	0.93	5.58	0.51	4.70	0.62	5.11	1.01
P_2O_5	0.26	0.03	0.24	0.14	0.19	0.17	0.05	0.06	0.15	0.09	0.10	0.08
LOI	0.63	0.23	0.58	0.35	0.84	0.23	0.75	0.11	0.77	0.24	0.58	0.29
TOTAL	99.07		99.67		99.56		99.50		99.50		99.57	
(ppm)												
Li	22.7	5.7	21.0	9.7	31.0	10.4	25.3	11.0	25.7	12.5	14.8	6.2
F	860.5	212.7	928.9	436.3	1298.0	410.7	1240.5	617.4	679.1	257.1	688.5	462.5
Sc	9.6	1.7	10.5	2.1	5.8	2.1	2.9	1.7	6.8	2.4	2.4	0.9
V	74.6	19.6	55.9	37.5	50.6	40.9	23.1	13.1	44.6	30.2	21.5	17.1
Cr	5.5	3.5	7.0	9.9	14.5	16.6	6.5	3.8	6.5	7.0	4.8	13.7
Ni	2.6	1.9	3.7	4.7	4.3	5.3	1.9	1.7	2.1	3.0	2.6	7.9
Cu	9.1	3.8	13.6	9.5	18.9	16.9	10.1	8.8	9.1	18.7	6.3	6.1
Zn	74.1	8.5	86.3	23.4	60.3	19.1	39.9	14.0	46.9	21.4	54.8	42.8
Ga	18.3	1.2	20.5	2.9	11.3	4.7	8.6	2.1	12.8	4.1	15.2	5.2
Rb	126.4	24.2	121.9	47.9	233.2	81.8	315.3	81.3	140.5	38.7	127.8	51.8
Sr	327.6	39.0	329.4	166.6	308.9	191.0	126.8	108.3	277.7	154.8	160.7	151.6
Y	36.5	1.9	39.2	13.6	30.3	8.7	27.8	7.6	28.2	10.2	42.5	17.2
Zr	236.6	83.2	486.3	255.9	408.0	190.7	345.0	140.0	240.0	83.8	368.8	210.3
Nb	14.2	1.1	19.1	8.5	21.2	8.1	29.0	8.6	13.6	4.4	19.1	7.2
Mo	4.3	0.5	4.1	1.0	4.7	1.5	4.3	2.7	3.2	1.2	3.7	1.2
Sn	1.0	0.0	2.7	2.7	6.1	4.2	7.2	4.2	3.9	3.3	2.7	2.7
Cs	1.3	1.2	1.6	1.7	10.7	5.3	9.0	4.3	4.1	1.8	0.7	0.6
Ba	1424.0	116.2	1099.0	558.0	742.8	360.6	381.9	352.6	961.5	542.3	660.8	482.6
La	53.3	4.9	64.8	31.7	50.7	13.1	56.3	22.9	50.6	14.8	63.1	30.2
Ce	102.7	6.1	131.0	63.2	108.3	30.3	114.0	43.7	100.1	28.5	126.8	59.2
Sm	9.2	0.8	13.3	3.1	8.2	1.7	6.9	1.7	9.3	3.0	10.4	3.9
Yb	2.5	0.0	3.8	2.1	4.1	1.0	4.5	0.9	2.5	0.0	4.2	2.0
Hf	8.0	1.2	11.9	3.5	12.2	3.0	9.9	3.1	12.5	21.1	10.1	3.0
Pb	15.9	3.9	15.9	6.6	17.8	6.1	23.4	8.0	16.8	8.1	17.6	11.2
Th	9.2	3.0	9.1	10.7	21.6	13.6	37.5	13.8	14.8	7.3	13.0	9.6
U	4.8	0.9	3.1	1.7	6.8	3.2	10.4	4.4	4.0	2.4	4.5	2.6
(Wt%)												
Q	12.25	1.76	8.02	6.40	10.94	6.32	22.13	7.27	22.14	8.29	22.16	9.88
C	0.00	0.00	0.05	0.18	0.02	0.10	0.12	0.24	0.26	0.36	0.06	0.14
Or	28.50	2.93	31.47	4.81	32.33	5.51	33.36	3.06	28.14	3.71	30.45	6.00
Ab	36.71	2.01	38.96	3.48	38.63	3.09	36.65	3.68	33.29	4.70	36.54	6.34
An	10.08	1.50	9.37	4.48	7.58	4.35	3.30	1.78	8.95	4.23	4.97	4.19
Di	2.88	1.35	2.85	1.48	2.60	2.33	0.79	0.82	0.43	0.74	1.11	1.66
Hy	4.65	1.72	4.53	2.26	3.90	2.08	1.41	1.11	3.77	2.10	1.81	1.34
Ol	0.00	0.00	0.41	1.09	0.25	1.80	0.00	0.00	0.00	0.00	0.18	1.60
Nt	2.64	0.55	2.41	0.96	2.03	0.96	1.36	0.59	1.76	0.90	1.60	0.82
Il	1.69	0.12	1.48	0.56	1.17	0.47	0.58	0.34	0.85	0.38	0.74	0.43

KEY TO UNITS (NIS - Numok Intrusive Suite MBIS - Mount Benedict Intrusive Suite)
10 -- Long Island Quartz Monzonite   48 -- Otter Lake - Walker Lake Cranitoid
20 -- (NIS) monzonite to quartz monzonite   30 -- Big River Granite
43 -- (MBIS) monzonite to syenite
44 -- (MBIS) syenite to granite

n1 -- Number of analyses for all elements except those listed below
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf

that the high Cu content of the Stag Bay unit is a function
of a single anomalous sample that has over 600 ppm Cu, and
is not representative of the unit as a whole.

The mean major element composition of the granitoid
gneiss unit is similar to means for either Makkovikian and
Labradorian plutonic assemblages. In view of the varied
lithology, this average cannot be considered representative
of this composite unit.

Abundance and Distribution of Rock Types

Relative proportions of IUGS rock types were calculated
from normative data after Streckeisen and LeMaitre (1979),
and are shown in Figure 6.2.

The Freshsteak and Noarse Lake units are generally
similar, but the Noarse Lake unit contains a higher
proportion of diorite and monzodiorite. The Stag Bay unit
is dominated by monzogranite with subordinate granite, and
the Jeanette Bay unit by granite, rather than quartz
syenite. The Thunder Mountain unit is of variable
composition, but is mostly quartz-poor (i.e. quartz diorite
to alkali-feldspar quartz syenite).

The large sample population for granitoid gneisses has
a bimodal pattern, dominated by granite to alkali-feldspar
granite, but with a smaller peak at quartz monzonite to
quartz syenite. This pattern resembles that shown by syn-
and post-tectonic Makkovikian plutonic associations
(Chapters 3 and 4).
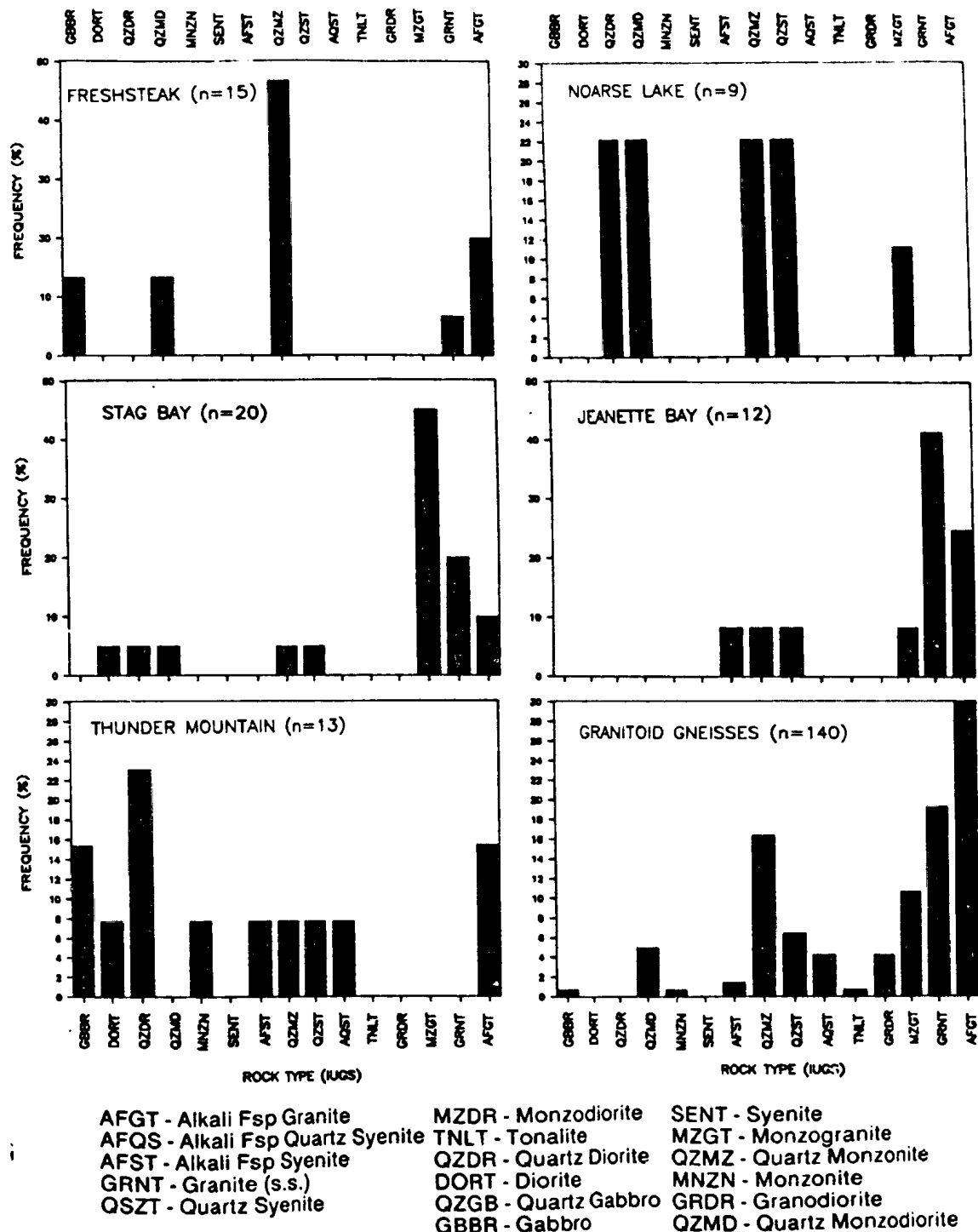
Figure 6.2 Relative abundance of IUGS rock types calculated from normative mineralogy after Streckeisen and LeMaitre (1979). Note that this is based on Barth mesonorms, not the CIPW norms listed in Table 6.2. Regional sample populations only.

AFGT - Alkali Fsp Granite
AFQS - Alkali Fsp Quartz Syenite
AFST - Alkali Fsp Syenite
GRNT - Granite (s.s.)
QSZT - Quartz Syenite

MZDR - Monzodiorite
TNLT - Tonalite
QZDR - Quartz Diorite
DORT - Diorite
QZGB - Quartz Gabbro
GBBR - Gabbro

SENT - Syenite
MZGT - Monzogranite
QZMZ - Quartz Monzonite
MNZN - Monzonite
GRDR - Granodiorite
QZMD - Quartz Monzodiorite
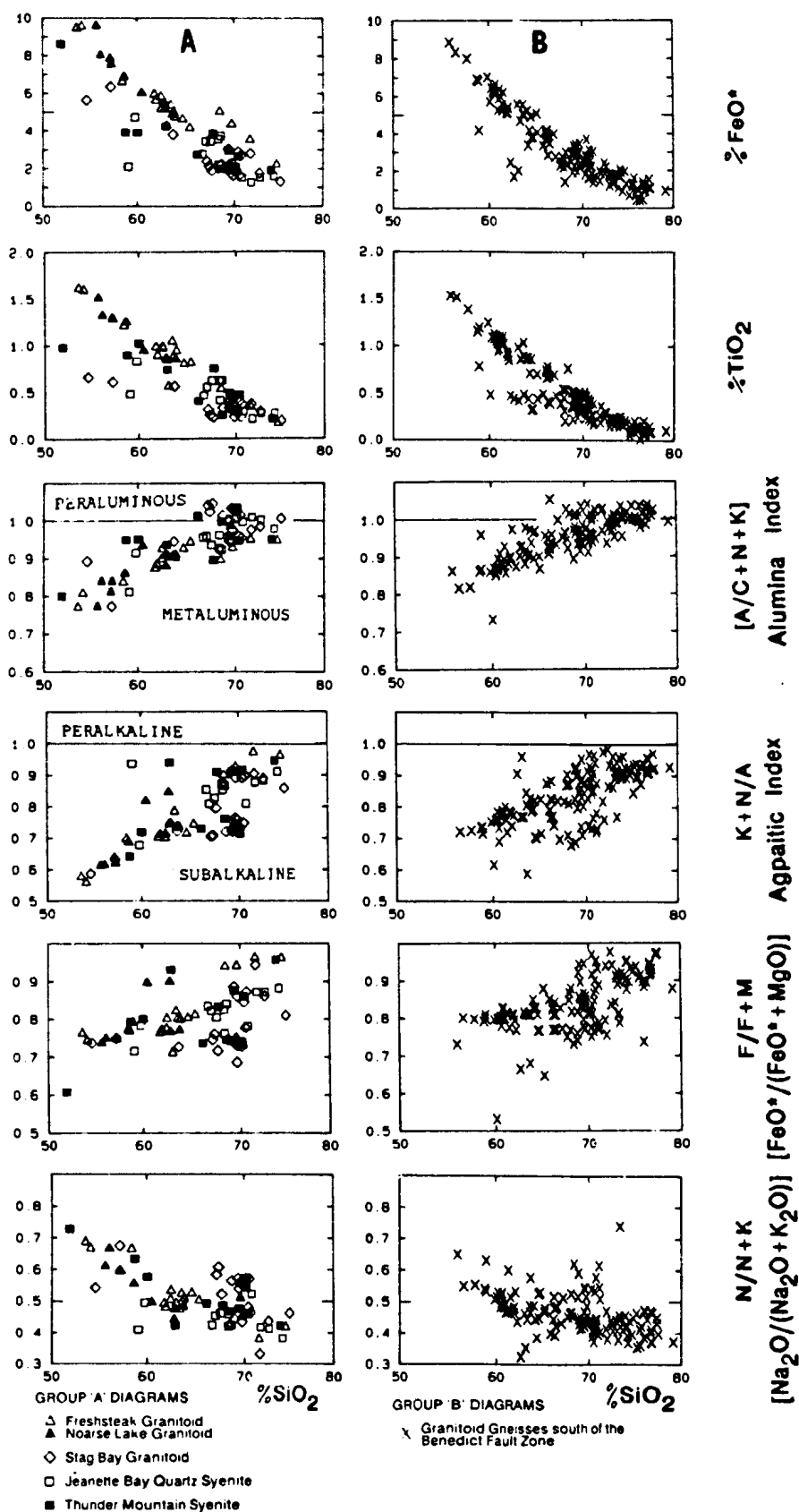
Figure 6.3. Variation of selected major elements and derived ratios in unclassified plutonic units. See text for discussion.

6.2.2 Geochemical Trends and Contrasts

Major Element Patterns

Major element patterns (Figure 6.3) follow expected trends and offer poor unit discrimination. High TiO_2 (also P_2O_5; not figured) contents below 65% SiO_2 (Figure 6.3) characterize the Freshsteak and Noarse Lake units. This feature is also shown by the petrographically similar Long Island Quartz Monzonite (Table 6.2; Figure 3.3, p.76)

All units show K+N/A (agpaitic index) values below 1.0. A/C+N+K indices are greater than 1.0 in part of the Stag Bay unit, and also in a few samples from Thunder Mountain and Jeanette Bay (Figure 6.3). All other units are wholly metaluminous. Parts of the Stag Bay unit have high (> 0.5) N/N+K ratios and low F/F+M (< 0.8) ratios above 60% SiO_2, compared to other units.

Major element patterns for the granitoid gneiss unit are similar to the overall pattern shown by discrete unclassified units (Figure 6.3). It includes no peralkaline compositions, but contains some peraluminous rocks.

Trace Element Patterns

Compatible OCC trace elements (e.g. V, Figure 6.4) do not discriminate between units. Rb and Th (Figure 6.4) are highest in the Jeanette Bay and Stag Bay units, consistent with their generally higher SiO_2. Sr, Ba and F (Figure 6.4) are scattered, but high Sr contents partly distinguish the Stag Bay unit. Zr, Y, Nb and Ce (Figure 6.5) provide no distinction between units, although there is some Y enrichment in the Freshsteak unit. Zn (Figure 6.5) is
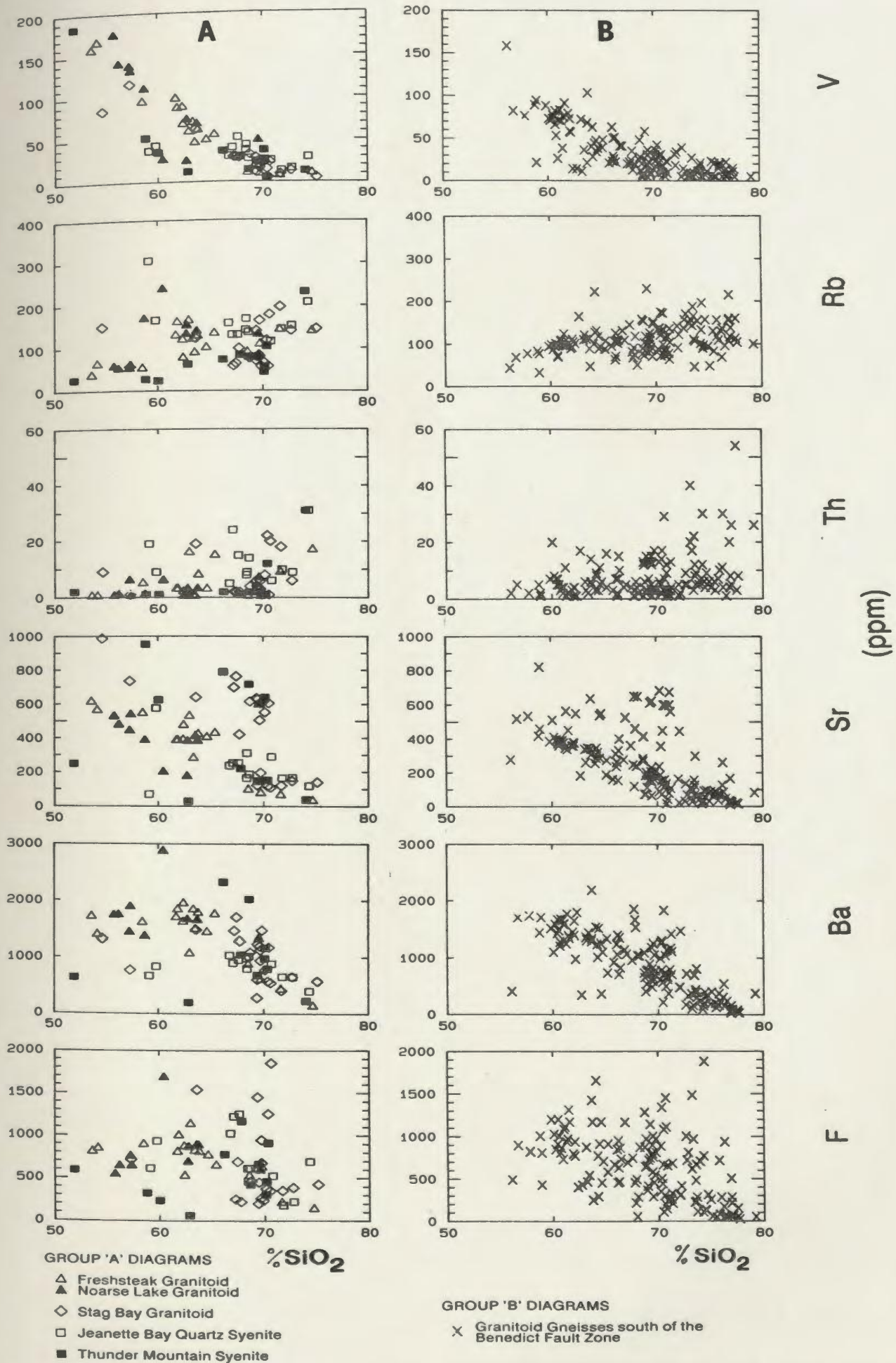
Figure 6.4. V, Rb, Th, Sr, Ba and F versus SiO$_2$ for unclassified plutonic units. See text for discussion.
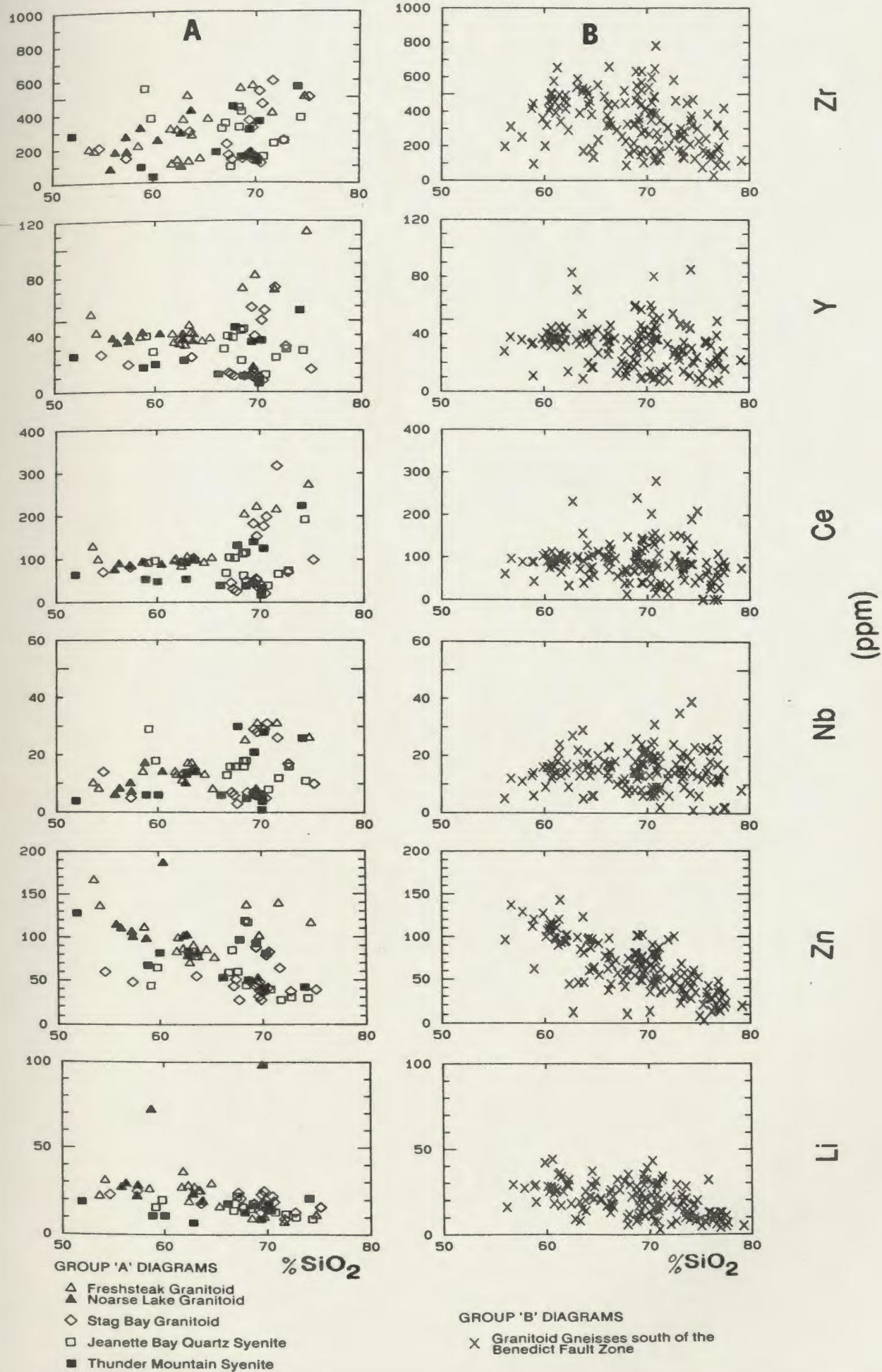
Figure 6.5. Zr, Nb, Y, Ce, Li and Zn versus SiO_2 for unclassified plutonic units. See text for discussion.
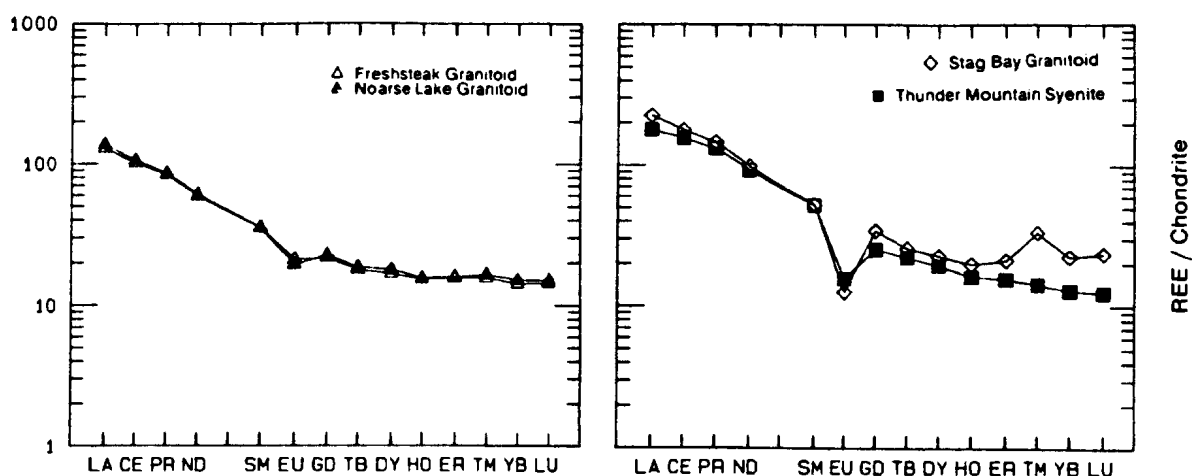
Figure 6.7. Rare Earth element (REE) patterns for representative
 unclassified plutonic rocks. Values are normalized to chondritic
 values (listed in Appendix C).

locally enriched in the Freshsteak and Noarse Lake units
above 70% SiO_2, and Li is enriched in some biotite-rich
rocks from the Noarse Lake unit.

The granitoid gneiss unit shows a similar range of
trace element variation. Scattered distributions for LFS
trace elements such as Th, Rb, Ba and Sr may in part
reflect element mobility during Grenvillian metamorphism,
rather than primary magmatic trends.

Rare Earth Element (REE) Patterns

Two samples from the Freshsteak and Noarse Lake units
have identical REE patterns (Figure 6.6). The Thunder
Mountain pattern is similar, but shows a larger negative Eu
anomaly. The Stag Bay unit has a dish-shaped MREE pattern,
similar to patterns observed in some Labradorian granitoids
(e.g. Figure 5.17, p.216). No data are available for the
granitoid gneiss unit.

6.3 SUMMARY and DISCUSSION

Geochemical contrasts between unclassified plutonic
units are subtle, and they cannot be classified as
Makkovikian or Labradorian on this basis alone. The
fluorine, HFS element and REE contents of these units fall
into the middle ground shared by both assemblages.

The Freshsteak and Noarse Lake units are, however,
petrographically and geochemically similar to the
Makkovikian Long Island quartz monzonite, particularly
with respect to their TiO_2 and P_2O_5 enrichment. A
general correlation between them is consistent with the
Rb-Sr age (1798 ± 48 Ma) obtained from the Freshsteak
Granitoid, which indicate a Makkovikian age (details in
Chapter 8).

Remaining unclassified units cannot be assigned with
confidence. The partially peraluminous composition of the
Stag Bay unit resembles that of some Labradorian
granitoids, and differs from compositions of typical
Makkovikian granitoids. The Jeanette Bay unit shows lower
incompatible element abundances than rocks of equivalent
composition in the adjacent Mount Benedict Intrusive Suite,
and is probably unrelated to them. The Thunder Mountain
Syenite is broadly similar to the Freshsteak and Noarse
Lake units in major and trace element composition, but
different in texture.

The granitoid gneiss unit overlaps in composition with
both Makkovikian and Labradorian plutonic assemblages, but
the distribution of rock types within it resembles the
former more closely. However, it lacks the marginally
peralkaline compositions typical of the Makkovikian
assemblage, and shows no extreme fluorine, HFS element and
REE enrichment. There is no firm basis for correlating it
with either Makkovikian or Labradorian associations alone,
and it probably includes reworked equivalents of both.

CHAPTER SEVEN
MAKKOVIKIAN AND LABRADORIAN
VOLCANIC ASSEMBLAGES

Chapter Abstract

The most extensive volcanic assemblage in the study area is the Upper Aillik Group, a complex Makkovikian sequence that includes at least two components of ca. 1860 and ca. 1810 Ma age. Geochemical studies of these rocks are hampered by widespread alkali-metasomatism, which appears to be a regional feature of this assemblage. In geochemical terms, unaltered variants are closely similar to Makkovikian high-silica granites such as the Kennedy Mountain, Strawberry and Lanceground Intrusive Suites, but do not show fluorine enrichment. They do, however, display borderline-peralkaline affinity, HFS element enrichment, and REE enrichment typical of most Makkovikian plutonic assemblages. Hypabyssal intrusive rocks within the Upper Aillik Group show the closest resemblance, and also display local fluorine enrichment. Alkali-metasomatism is closely similar to analogous patterns recognized in the syn-tectonic Kennedy Mountain Intrusive Suite.

It is suggested here that the Upper Aillik Group is a two-stage sequence comprising broad equivalents of syn- and post-tectonic Makkovikian plutonic rocks. This is consistent with geochronological data from both groups, which overlap in part. However, ca. 1860 Ma volcanic rocks predate most of the syn-tectonic plutons, and younger post-tectonic granites such as the Strawberry Intrusive Suite may be significantly younger than 1800 Ma.

The Bruce River Group (described by Ryan, 1984) includes a Labradorian bimodal (felsic > mafic) volcanic sequence. Although similar to the Upper Aillik Group in terms of major element chemistry (particularly in felsic compositions), this sequence evolves to peraluminous compositions, and has lower HFS element and REE abundances. On the basis of map patterns, it appears to contain a higher proportion of basaltic and basaltic andesite compositions than the Upper Aillik Group. Such features are consistent with the mafic compositions observed in the Labradorian plutonic assemblage, and with subtle geochemical contrasts noted between Makkovikian and Labradorian plutonic assemblages.

Volcanic sequences in the Benedict Mountains (here termed Jagged Edge assemblage) have previously been grouped with the Upper Aillik Group. In geochemical terms, however, they resemble the Labradorian Bruce River Group, and may be a younger sequence. However, they are geochemically distinct from local Labradorian plutonic rocks of the Mount Benedict Intrusive Suite.

Introduction

Volcanic and metavolcanic assemblages were not examined
in detail during this project, but are an important
component of Proterozoic magmatism in the study area. This
chapter is mostly concerned with their possible relationship
to plutonic associations described in preceding chapters.
Descriptions are based partly on previous work (Bailey,
1979; Evans, 1980; Gower at al., 1982) and partly on the
author's more limited observations in selected areas.

The most extensive volcanic assemblage is the
Makkovikian Upper Aillik Group, which is dominated by rocks
of felsic composition, with minor mafic metavolcanic rocks.
The Bruce River Group, exposed beyond the western boundary
of the study area, includes a thick sequence of mafic and
felsic volcanic rocks, and is of Labradorian age. Volcanic
rocks also form several discontinous belts in the Benedict
Mountains, which have previously been correlated with the
Upper Aillik Group. The term "Jagged Edge assemblage" is
used below as a label of convenience for these, although it
is recognized that they may actually be part of the Upper
Aillik Group sequence.

7.1 GEOLOGY and PETROLOGY

7.1.1 Upper Aillik Group (Type Area Only)

General Overview

The Upper Aillik Group has the dubious distinction of
being the most studied yet least understood Proterozoic
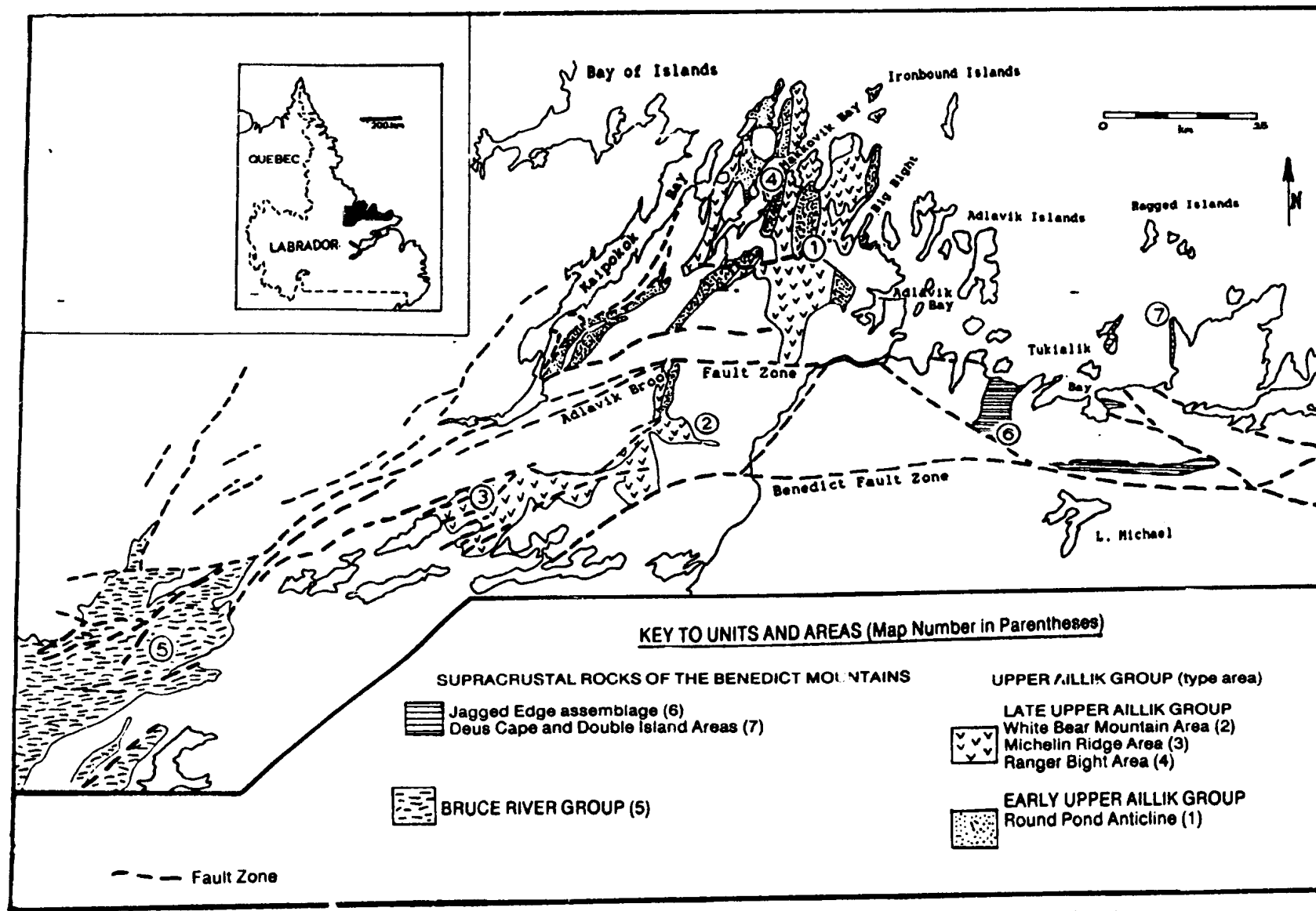
Figure 7.1. Summary map illustrating the distribution and extent
of Makkovikian and Labradorian volcanic assemblages.

Within the figure:

Bay of Islands

Ironbound Islands

Adlavik Islands

Ragged Islands

QUEBEC

LABRADOR

200 km

Makkovik Bay

Big Bight

Adlavik Bay

Tukialik Bay

Kaipokok Bay

Adlavik Brook

Fault Zone

Benedict Fault Zone

L. Michael

KEY TO UNITS AND AREAS (Map Number in Parentheses)

SUPRACRUSTAL ROCKS OF THE BENEDICT MOUNTAINS

Jagged Edge assemblage (6)
Deus Cape and Double Island Areas (7)

BRUCE RIVER GROUP (5)

UPPER AILLIK GROUP (type area)

LATE UPPER AILLIK GROUP
White Bear Mountain Area (2)
Michelin Ridge Area (3)
Ranger Bight Area (4)

EARLY UPPER AILLIK GROUP
Round Pond Anticline (1)

— — — Fault Zone

- 263 -

sequence in eastern Labrador. This reflects rapid lateral facies changes that complicate its stratigraphy, and the variable overprint of greenschist to lower amphibolite facies metamorphism and associated deformation (Gower et al., 1982; Gower and Ryan, 1987). Parts of the sequence are structurally complex and polydeformed (e.g. Clark, 1973), but (paradoxically) some rhyolites and hypabyssal intrusive rocks are massive or only weakly cleaved (e.g. Bailey, 1979). Metamorphic grades range from lower amphibolite near Kaipokok Bay, to sub-greenschist in the east and south of the area (Gower et al., 1982).

The sequence is most extensive in the north of the study area, where it is areally dominant over plutonic units. It also forms a narrow zone extending into the southwest of the area, where it is bounded mostly by faults. This area (termed the Michelin area) has been the focus of most previous studies (e.g Bailey, 1979; Evans, 1980; White and Martin, 1980).

No systematic mapping of the Upper Aillik Group was conducted during this project, but the sequence was examined in a number of coastal areas, and also during helicopter and ground mapping of adjacent plutonic rocks. Upper Aillik Group country rock types were sampled routinely for geochemistry, but no grid sampling program was undertaken over these units.

Concepts of Aillik Group Stratigraphy

The term "Aillik Series" was proposed initially by Kranck (1939), and subsequently modified to "Aillik Group" by King (1963). Many of the rocks now grouped in the upper portion were initially described as quartzite, arkose, feldspathic quartzite and banded quartzite - misnomers that

reflect the saccharoidal textures of many recrystallized rocks exposed on the coast. King (1963), Clark (1973) and White (1973) recognized that at least some of these siliceous rocks were of volcanic origin, and this was subsequently confirmed on a regional scale (e.g. Gandhi, 1978; Bailey, 1979; Gower et al., 1982).

The contact between Lower and Upper Aillik Groups is tectonized, and, despite repeated examination (Marten, 1977; Evans, 1980; Wardle, pers. comm., 1985), no concensus has emerged regarding its significance. Marten (1977) suggested that deformed conglomerate at the base of the Upper Aillik Group (which contains clasts typical of the Lower Aillik Group) represents a major unconformity. There is concensus that the Upper Aillik Group has a generally simpler structural style than the Lower Aillik Group, which has undergone isoclinal folding and thrusting (Marten, 1977). There are, however, equally strong contrasts in deformation state within the Upper Aillik Group (Gower et al., 1982; Gower and Ryan, 1987)

These contradictions led to a revised concept of Upper Aillik Group stratigraphy, in which it was divided into an "early" and "late" component (Gower and Ryan, 1987). The late Upper Aillik Group is dominated by felsic volcanic rocks, whereas the early portion comprises a mixed volcanic and clastic sedimentary assemblage. It was suggested that these early and late components could be separated by a mafic metavolcanic marker horizon. Gower and Ryan (1987) further speculated that early and late components correlated with syn-tectonic and post-tectonic plutonic assemblages respectively; the latter were at that time considered to be wholly of ca. 1650 Ma (Labradorian) age. Schärer et al. (1988) subsequently reported U-Pb zircon ages of 1856 +/- 2 Ma and 1807 +/- 3 Ma from two separate localities assigned

by Gower and Ryan (1987) to the late Upper Aillik Group. A
rhyolite flow interbedded with volcaniclastic sediments that
are probably part of the early sequence gave a U-Pb zircon
age of 1861 + 9/- 3 Ma (Schärer et al., 1988). These ages
appear to rule out a relationship between the Upper Aillik
Group and Labradorian plutonic rocks.

The two-stage stratigraphic concept is, however, still
valid in the light of new Rb-Sr and U-Pb zircon data (this
study and Krogh et al., in prep.). Post-tectonic Makkovikian
plutonic rocks dated at ca. 1800 Ma are similar in age to
the youngest rocks recognized within the Upper Aillik Group,
and to some of their syn-tectonic, foliated counterparts. It
is suggested here that early and late components of the
Upper Aillik Group correspond broadly to syn-tectonic and
post-tectonic Makkovikian plutonic associations, and that
an unconformity or discontinuity may be present within the
sequence. However, contrasts in deformation state amongst
the metavolcanic rocks may also be a function of
inhomogeneous deformation, as discussed for equivalent
plutonic assemblages (Chapter 4). There is, however, no
evidence of plutonic rocks of equivalent age to the earliest
rocks (ca. 1850 Ma) recognized in the Upper Aillik Group.
The oldest age yet obtained from plutonic rocks is ca. 1840
Ma (Deus Cape Granitoid; Krogh et al., in ~ep.), although
Gandhi et al. (1988) report ages of ca. 1₂ ₃ Ma to the west
of the Study area.

This interpretation must be confirmed by systematic
mapping of the Upper Aillik Group, and by dating its
components with reference to stratigraphy. The central
problem is the delineation of early ε ₃ late components,
complicated by the possibility that the mafic volcanic
"marker" may not be the same unit everywhere, a conclusion
supported by recent geochemical data (MacDougall, 1988).

Undeformed granitoid rocks invariably intrude the Upper
Aillik Group. Foliated Makkovikian plutonic rocks also
appear to post-date adjacent supracrustal rocks, but in most
areas these correspond to the early Upper Aillik Group of
Gower and Ryan (1987). However, the inverse relationship
(i.e. Upper Aillik Group hypabyssal intrusive lithologies
intruding older granitoid rocks) would be indistinguishable
from normal outcrop-scale details observed in most granitoid
units. Also, many plutons are known to intrude their own
ejecta as a consequence of the greater longevity of plutonic
systems and cauldron subsidence (e.g. Lipman, 1988).

Early Upper Aillik Group

The early Upper Aillik Group, as outlined by Gower and
Ryan (1987), forms the core of an anticline at Round Pond,
and also three broadly parallel belts that are infolded with
the predominant later sequence (Figure 7.1). It also occurs
in minor amounts in the southwest of the area. It has not
been examined in detail during this study, and descriptions
below are summarized from Gower et al. (1982).

The sequence is lithologically varied, but dominated by
metasedimentary rocks. These include arkose, banded tuff,
laminated arenite, siltstone, pebble conglomerate and
breccia with volcanic clasts. Subordinate volcanic rocks
include dacite-rhyolite compositions, and lesser mafic flows
and tuffs. The top of the sequence is supposedly defined by
the "marker" mafic- intermediate tuff horizon, which locally
includes pillow lavas and possible subaerial volcanic rocks.
The rock types present immediately below this unit are
laterally variable; this could indicate rapid lateral facies
changes, the presence of an angular unconformity at its
base, or both (Gower and Ryan, 1987). Alternatively, as

discussed above, it may indicate the presence of more than one "marker" horizon within the sequence. The early Upper Aillik Group is deformed and metamorphosed in most areas. Deformation is most evident in lithologies such as conglomerate, which show intense flattening, but most other rock types are also completely recrystallized.

General Features of the Late Upper Aillik Group

The late Upper Aillik Group, as outlined by Gower and Ryan (1987), corresponds essentially to unit 9 of Gower et al. (1982). It is dominated by felsic volcanic and pyroclastic rocks, with lesser tuffaceous arkose and sandstone. It also includes hypabyssal intrusive rocks. All of these were examined during this project, but geochemical sampling is biased towards areas marginal to plutonic bodies. Recrystallization during regional metamorphism, particularly in the northwest, and thermal metamorphism around younger intrusions, have destroyed primary volcanic textures in most areas. In general, recrystallization is more intense in extrusive rock types than in the hypabyssal intrusive rocks. General characteristics of these rocks are illustrated in Plate 7.1.

Volcanic, Pyrolclastic and Volcaniclastic Rocks

Field Relations and Lithology : Outcrops are commonly heterogeneous. The best candidate for a "dominant" lithology is a fine to very fine-grained, pink to grey or buff, variably banded metavolcanic rock that has a saccharoidal texture. Volcanic textures are only rarely preserved, and in many cases it is impossible to differentiate between massive rhyolite and crystal tuff. Larger grains of quartz,
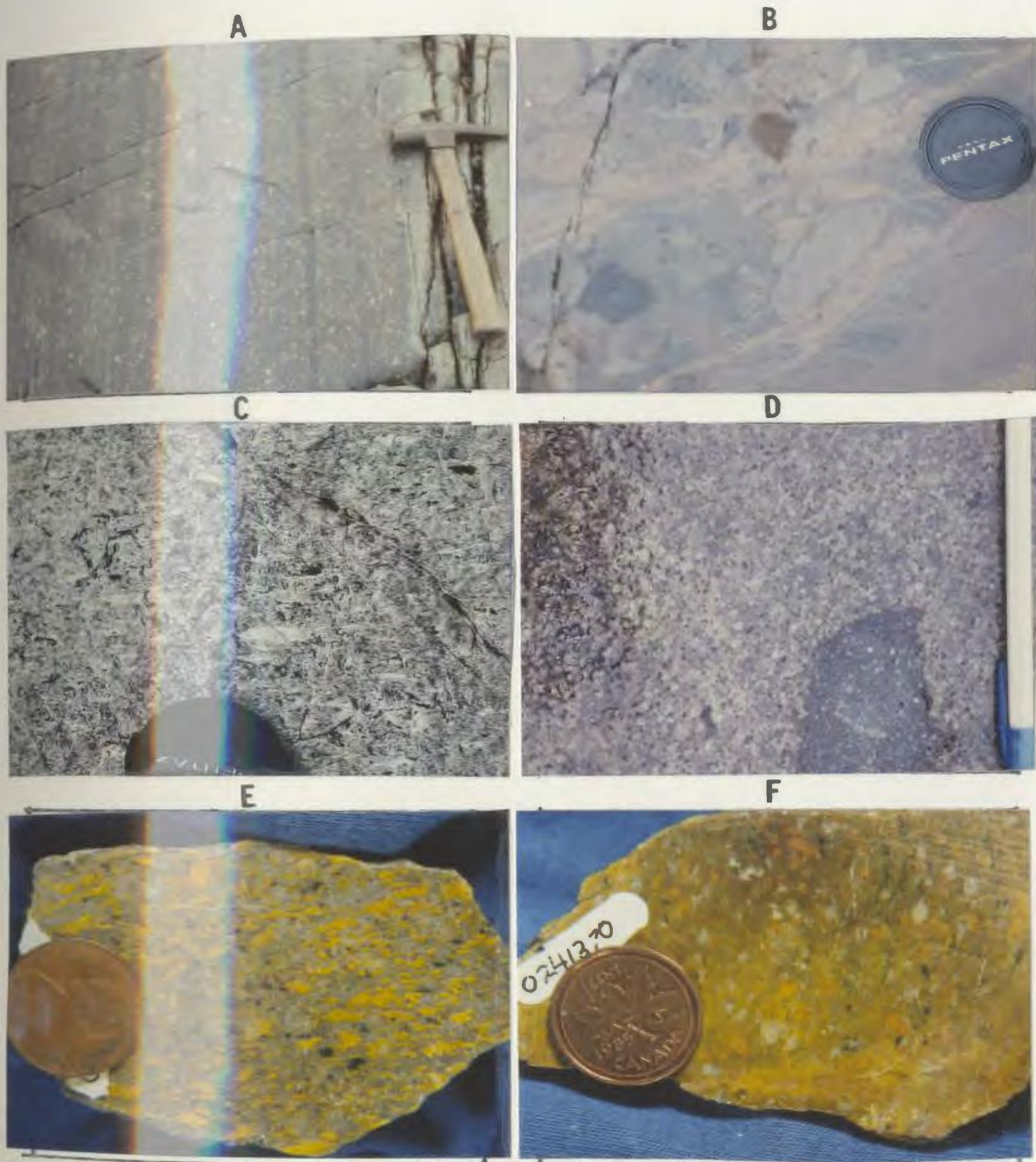
Plate 7.1 Features of the Upper Aillik Group (see also Plate 7.2).
(a) Flow-banded, porphyritic rhyolite, Manak Bay area. (b) Rhyolite
breccia, with rounded clasts of porphyry and flow-banded rhyolite,
Manak Bay area. (c) Recrystallized tuff with deformed lithic
fragments, Ranger Bight. (d) Purple feldspar-porphyry, including part
of a rhyolite xenolith, Ironbound Islands. (e) and (f) Typical
enigmatic Upper Aillik Group lithologies, that could be flows or
pyroclastic rocks. Slabs stained for K-feldspar.

K-feldspar and plagioclase are commonly present, and
represent either phenocrysts or crystal fragments. Banding
is locally recognizable as a primary flow-banding, but
relict fragmental textures suggest that it may also result
from strong deformation of lithic tuff or agglomerate.
Lithic fragments, in many cases recognisable only as
blotches or diffuse ellipsoids, occur widely and, unless
they represent xenoliths in rhyolitic flows, indicate a
fragmental origin for much of the recrystallized material.
The few areas where Upper Aillik group volcanic rocks
preserve original volcanic textures (e.g. at Ranger Bight in
Makkovik Bay, and at Michelin Ridge) also consist dominantly
of pyroclastic material that resembles ash-flow tuff,
associated with subordinate rhyolite flows.

Petrography : Pervasive recrystallization has
obliterated most original textures, leaving a groundmass of
very fine grained quartz and feldspar. Broken crystals or
phenocrysts are preserved as coarser grain aggregates. The
most common "phenocryst" phases are K-feldspar and
plagioclase; quartz is less abundant. The mafic mineral
assemblage in most samples has been degraded to aggregates
of iron oxide, sphene, chlorite and epidote. Amphibole
(actinolite, more rarely hornblende) and pyroxene are
present locally. Blue amphibole of sodic composition,
associated with accessory fluorite, is a distinctive
component in some areas, particularly adjacent to some
small granitoid plutons in the north. It is uncertain
whether this is a primary or metasomatic feature, since
metasomatic effects involved with mineralization and/or
granitoid intrusion have been documented in several areas
(White and Martin, 1980; Evans, 1980; Kerr, 1988; see also

sections 3.3 and 7.2). Upper Aillik Group rocks are not commonly fluorite-bearing, except in areas adjacent to plutonic units.

Hypabyssal Intrusive Rocks

Field Relations and Lithology : Massive feldspar and quartz-feldspar porphyry form several mappable bodies, and also occur as dykes and veins on an outcrop scale within the metavolcanic rocks. The largest body, at White Bear Mountain, consists of purple or grey porphyry with large (up to 2 cm) K-feldspar phenocrysts and less abundant, smaller, rounded, blue quartz eyes. Similar (but less spectacular) rock types are present near Round Pond (MacDougall, 1988), south of Cape Strawberry, and on offshore Islands north of Cape Strawberry. Relationships between these and the dominant metavolcanic rocks were not examined in this study. Bailey (1981) suggested that subvolcanic intrusive rocks passed gradationally into felsic volcanic rocks in several areas.

Petrography : Samples from White Bear Mountain consist of a recrystallized microcrystalline groundmass assemblage of quartz, microcline and sodic plagioclase, that locally retains a granophyric texture. Euhedral to ovoidal perthitic microcline phenocrysts locally show rims of sodic plagioclase. Quartz phenocrysts are less common; in places they have a bipyramidal habit suggesting that they were originally a high-temperature polymorph (Payette and Martin, 1986). Fine aggregates of biotite and chlorite are present in most samples, blue-green amphibole occurs locally, but the most obvious mafic species are opaque oxides associated

with granular sphene. Other Upper Aillik Group porphyry
bodies are similar in mineralogy, and commonly show less
evidence of recrystallization than adjacent metavolcanic
rocks.

7.1.2 Supracrustal Rocks of The Benedict Mountains (Jagged Edge Assemblage)

General Overview

The label "Jagged Edge assemblage" is used here for
felsic volcanic and volcaniclastic rocks in the east of the
study area (Figure 7.1), that are geographically isolated
from the type area of the Upper Aillik Group. Gower (1981)
correlated these with the type area (7.1.1), but stated that
their equivalence was mostly an assumption. The name is
introduced mostly to avoid tedious repetition of the phrase
"volcanic sequences of the Benedict Mountains area". There
is however, no guarantee that all these belts are of the
same age or affinity. However, if dextral displacement along
the suggested continuation of the Adlavik Brook Fault zone
is removed (Figure 7.1), most of them coalesce into a single
discontinuous unit. Occurrences on the mainland were
examined and sampled during this project; those on Double
Island and near Deus Cape were not visited, but are
described by Gower (1981). Archibald and Farrar (1979)
report an Ar-Ar age of 1630 ± 10 Ma from muscovite in a
pegmatite pod within volcanic rocks southeast of Stag Bay,
which provides a younger limit on the age of the sequence.
Typical features of these rocks are illustrated in Plate
7.2.
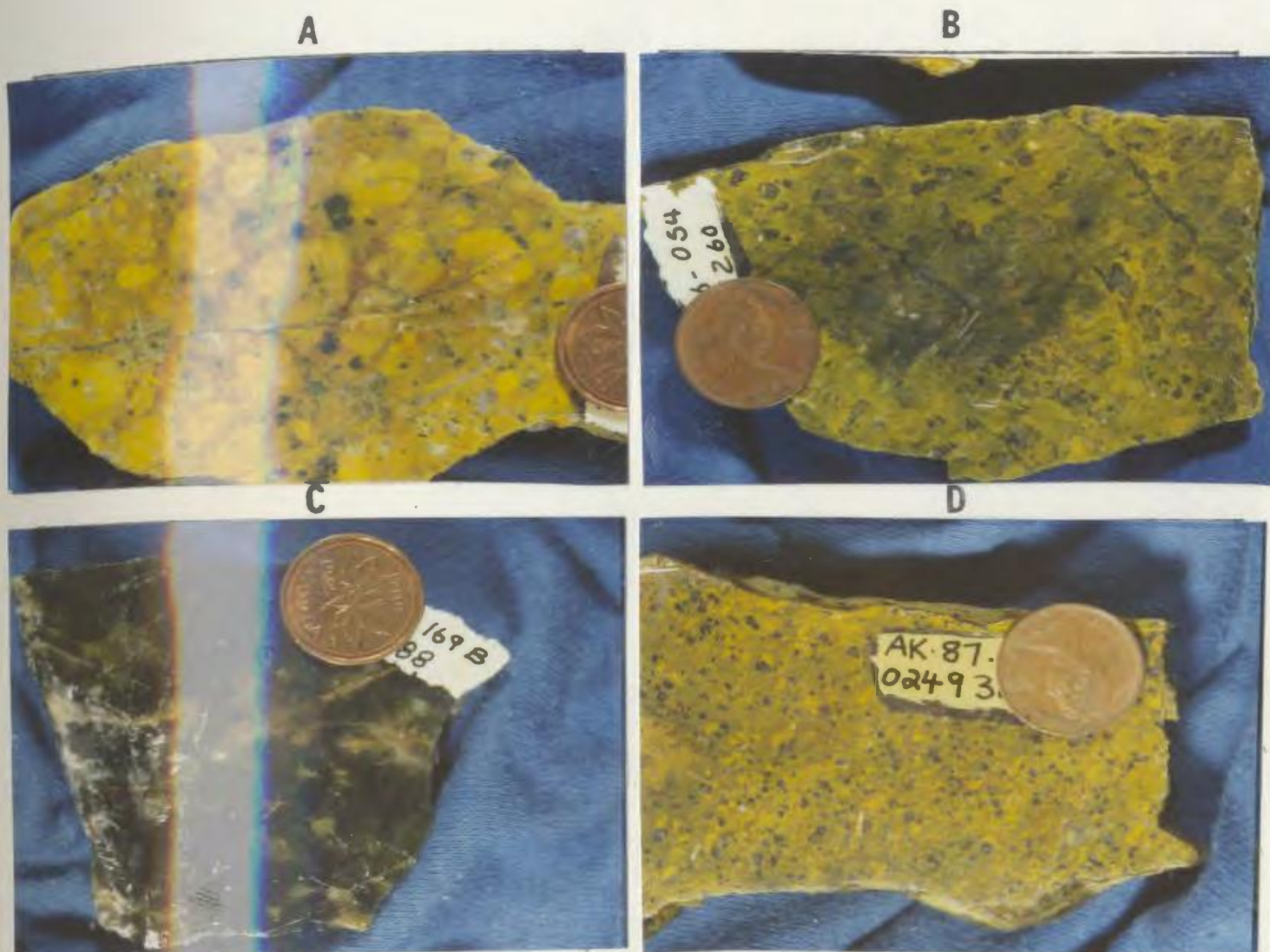
Plate 7.2 Features of the Upper Aillik Group and the Jagged Edge
Assemblage. (a) and (b) Quartz-porphyry and quartz-feldspar porphyry
from White Bear Mountain area. (c) Glassy, silicified rhyolite with
spherulitic appearance, Jagged Edge. (d) Fine-grained, very fresh,
quartz-feldspar porphyry, Jagged Edge. Slabs stained for K-feldspar.

Field Relations and Lithology

The best exposures are in a rugged area east of Stag Bay (Figure 7.1), and comprise a sequence of pink, grey and purple-brown felsic tuffs, agglomerates, flows(?), and hypabyssal intrusive rocks associated with lesser volcaniclastic sedimentary rocks (Gower, 1981). The agglomerates are essentially undeformed, and contain rhyolite fragments up to 30 cm in diameter. A distinctive lithology observed during this project is a grey, extremely hard, highly siliceous tuff that locally retains flattened shard-like fragment shapes and spherulitic textures. Massive, undeformed, grey to purple feldspar-porphyry (and lesser quartz-feldspar porphyry) is also present.

East of Tukialik Bay, a similar assemblage of rock types forms a triangular enclave within the Tukialik Granite. D.Bailey (pers.comm to C.F.Gower, 1979) suggested that these may have a gradational relationship with the surrounding granite, but they are cut locally by granite veins (however, these veins are not obviously similar to the nearby Tukialik Granite). Volcanic rocks are also present in an elongate, east-trending belt immediately north of the Benedict fault zone that, based on its strongly sheared appearance, is interpreted as a fault-bounded sliver. Original characteristics in this area have mostly been destroyed by cataclasis, and it is possible that some banded, rhyolite-like rocks are in fact mylonites. However, quartz-eye and fragmental textures are locally preserved.

Supracrustal rocks also occur on Double Island, and as a narrow coastal strip south of Deus Cape. Gower (1981) reports more intense deformation in these areas, and a higher proportion of metasedimentary material. These descriptions are reminiscent of the early Upper Aillik Group

of Gower and Ryan (1987). It is therefore possible that
"Jagged Edge assemblage" also includes more than one
sequence; geochemical features discussed here (7.2) apply
only to the fresher rocks exposed on the mainland.

7.1.3 Bruce River Group

General Overview

The Bruce River Group (defined initially by Smyth et
al., 1978) is a well-preserved volcanosedimentary sequence
exposed beyond the western boundary of the study area
(Figure 7.1). It has been examined only in scattered
localities during this study but, as geochemical data are
used below for comparative purposes, a brief review (drawn
from Ryan, 1984, and Ryan et al., 1987) is included here.

The Bruce River Group rests unconformably upon the
pre-Makkovikian Moran Lake Group, and is affected only by
Grenvillian deformation. It has a well-defined stratigraphy
consisting of three formations defined by Ryan (1984). The
two lower formations are dominated by terrestrial
sedimentary rocks, whereas the uppermost and thickest
(Sylvia Lake Formation) comprises a bimodal (felsic > mafic)
volcanic assemblage.

Previous Rb-Sr geochronological studies (Wanless and
Loveridge, 1972; Kontak, in Ryan, 1984) suggested ages of
1530 to 1510 Ma for the volcanic rocks. U-Pb zircon dating
(Schärer et al., 1988) yielded 1649 +/- 1 Ma for a rhyolite,
indicating that it is of Labradorian age. It is the only
known Labradorian volcanic assemblage in eastern Labrador,
although parts of the Petskapiskau group in central Labrador
have yielded Labradorian ages (Krogh, 1985). .

Field Relations and Lithology

The lowermost (Heggart Lake) formation is a laterally discontinous package of conglomerate, sandstone, arkose and lesser mafic flows. The overlying Brown Lake Formation consists dominantly of conglomerates and arenites containing significant amounts of volcanic detritus. The uppermost (Sylvia Lake) formation is over 8 km thick, and consists of mafic and felsic (and minor intermediate) volcanic rocks, agglomerates, breccias and (especially in the upper part) welded and non-welded tuff. Ryan et al. (1987) distinguish two large-scale cycles of volcanism, that each commence with mafic and intermediate rocks, and culminate in thick felsic sequences. They estimate the ratio of felsic to mafic/intermediate rocks as approximately 2.2:1; the intermediate compositions are rare. On the basis of outcrop areas, the sequence appears to contain a higher proportion of mafic volcanic rocks than the Upper Aillik Group.

Mafic and intermediate volcanic rocks comprise grey to green, vesicular and/or porphyritic flows containing phenocrysts of plagioclase and clinopyroxene, with lesser orthopyroxene and olivine. Felsic rocks are dominated by grey, red, green or purplish welded ash-flow tuffs with prominent fragments and/or phenocrysts of feldspar. Well-preserved original features include eutaxitic foliations and lithophysae. Coarse fragmental rocks occur locally, as do cross-bedded (aeolian?) sandstones. Detailed petrographic descriptions of the volcanic rocks are presented by Ryan (1984).

7.2 DESCRIPTIVE GEOCHEMISTRY

Volcanic and hypabyssal intrusive rocks sampled during this project are represented by a total of 73 analyses. No distinction is made below between regional, follow-up and geological sample populations, as grid sampling systems were not employed. Most of the samples were collected in areas adjacent to intrusive rocks. Data presented here do, however, provide a good indication of the compositional spectrum of the Upper Aillik Group as, unlike most previous studies (see below), they were collected without reference to mineralized areas. Comparative data from the Bruce River Group used below are from Ryan (1984).

7.2.1 Previous Studies

Several geochemical studies of the Upper Aillik Group have been conducted in areas of uranium mineralization, particularly in the Michelin area. These rocks have variously been described as calc-alkaline, alkaline or peralkaline in affinity.

Geochemical investigations are hampered by strong compositional (particularly alkali) disturbance, recognized initially by White (1976) and White and Martin (1980). White and Martin (1980) concluded that the rocks of the Michelin area were originally of alkaline composition, but were affected by Na-metasomatism and desilication, and by lower-temperature K-metasomatism, both associated with mobility of U and Zr.

Subsequent studies in the same area by Evans (1980) further emphasized the links between metasomatism and

uranium mineralization and suggested that metasomatism took place via cation-exchange and substitution of Na-Al for Si in feldspars. A high-K calc-alkaline affinity was suggested for the sequence as a whole. Similar conclusions were reached by Bailey (1979) and Wardle and Bailey (1981). Gower et al.(1982) did not speculate on such matters, but pointed out that there were geochemical differences between the early and late components of the Upper Aillik Group.

Payette and Martin (1986), working also in the Michelin area, attempted to circumvent metasomatic complications by analyzing "melt inclusions", i.e., tiny glassy pockets that represent globules of magma trapped in growing phenocrysts. However, microprobe analyses revealed strong alkali variation amongst inclusions, implying that even these did not escape compositional disturbance. They suggested that an alkaline magma was most consistent with the observed compositional range of melt inclusions. MacDougall (1988) examined the sequence in the mineralized Round Pond area, and suggested a bimodal compositional spectrum, partly reflecting the presence of one of the few mafic units in the sequence in this area. He documented metasomatic patterns analogous to those of the Michelin area, and suggested that apparent peralkaline compositions were due to alteration.

Ryan (1984), and Ryan et al.(1987) conducted petrochemical studies on the Bruce River Group. This sequence appears to be less disturbed than the Aillik Group; they also suggested that it had affinities to high-K calc-alkaline sequences, at both mafic and felsic ends of its compositional spectrum.

Table 7.1 . Average compositions of Makkovikian and Labradorian
volcanic assemblages. Bruce River Group data from Ryan (1984).

UNIT	1.0		1.0 (unaltd)		1.1		1.2		1.2 (unaltd)		1.3		1.4	
n1	13		6		5		16		9		14		21	
n2	3		1		5		15		9		13		6	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	72.81	3.54	73.12	3.54	75.42	1.56	74.26	3.29	74.53	1.79	71.27	3.99	71.62	4.37
TiO2	0.32	0.22	0.35	0.16	0.22	0.08	0.23	0.11	0.20	0.09	0.36	0.11	0.26	0.13
Al2O3	13.61	1.59	13.25	1.86	11.75	0.24	12.49	1.35	12.39	0.96	13.61	1.80	14.15	2.08
Fe2O3	1.47	1.10	2.00	0.95	1.86	0.78	1.65	0.56	1.57	0.58	1.82	0.88	1.28	0.55
FeO	0.60	0.62	0.24	0.18	1.20	0.50	0.77	0.67	0.81	0.55	0.79	0.46	0.70	0.51
MnO	0.04	0.02	0.05	0.02	0.05	0.02	0.04	0.02	0.04	0.02	0.06	0.02	0.05	0.02
MgO	0.44	0.40	0.25	0.17	0.07	0.06	0.23	0.52	0.10	0.09	0.28	0.28	0.50	0.55
CaO	1.09	0.93	0.86	0.67	0.52	0.22	0.59	0.59	0.55	0.27	1.19	1.13	1.40	1.13
Na2O	4.02	1.90	3.72	1.01	5.62	1.60	4.08	1.62	4.12	0.48	3.90	0.28	3.72	1.10
K2O	4.67	2.89	5.08	0.88	2.22	2.17	4.77	2.81	4.71	0.52	5.52	0.45	4.81	1.17
P2O5	0.07	0.06	0.06	0.04	0.02	0.00	0.03	0.03	0.03	0.02	0.04	0.04	0.06	0.04
LOI	0.69	0.38	0.68	0.37	0.46	0.28	0.44	0.22	0.39	0.13	0.57	0.31	0.95	0.72
TOTAL	99.83		99.64		99.41		99.58		99.44		99.41		99.49	

(ppm)	Trace Elements													
Li	16.5	19.0	13.5	12.2	7.4	8.8	11.7	15.4	16.2	19.7	13.1	6.2	19.0	14.7
F	378.5	339.8	384.0	290.1	331.8	346.3	272.0	401.2	419.1	491.5	541.1	34?.2	540.7	491.0
Sc	1.7	0.9	0.7	0.0	1.8	1.4	2.2	1.9	1.8	1.3	4.8	2.7	3.4	1.4
V	21.1	9.6	22.0	6.5	11.4	1.7	18.4	22.1	13.0	6.9	13.3	9.9	25.8	14.8
Cr	6.0	10.4	3.3	2.7	7.2	11.8	7.6	8.2	7.8	9.1	5.9	3.7	19.0	55.3
Ni	2.5	3.3	1.5	0.8	5.4	9.8	1.4	1.5	1.0	0.0	2.0	2.8	5.3	14.9
Cu	4.2	3.4	2.0	1.5	14.6	24.3	4.7	3.7	4.4	3.3	6.9	8.8	6.9	5.1
Zn	44.0	34.1	52.0	47.1	66.8	64.9	86.1	81.0	112.2	94.8	77.8	41.7	44.9	22.9
Ga	12.6	4.3	12.3	5.0	24.2	6.7	15.4	6.9	16.7	7.9	11.5	6.7	7.8	1.7
Rb	138.1	105.8	134.8	26.8	56.4	48.2	139.4	86.2	149.4	48.8	168.2	28.8	156.3	58.2
Sr	156.4	144.7	142.3	157.3	48.8	35.1	53.4	46.3	57.2	50.5	140.9	226.4	216.6	187.0
Y	32.0	24.3	33.3	20.3	71.2	22.4	54.7	32.2	69.1	31.0	69.9	17.1	25.2	9.4
Zr	317.3	155.6	407.7	137.2	593.6	354.3	529.8	264.6	550.2	338.7	490.4	129.4	262.5	78.8
Nb	15.5	7.1	18.7	4.5	33.8	19.5	27.8	10.7	30.4	11.0	29.2	7.6	14.2	5.6
Mo	2.9	1.2	2.5	1.0	14.0	22.5	7.4	15.2	4.7	5.9	2.8	1.1	2.6	0.9
Sn	3.0	3.5	1.0	0.0	9.2	9.4	5.2	2.8	6.1	3.1	6.4	2.9	2.3	1.4
Cs	1.0	0.9	0.5	0.0	0.5	0.0	1.0	0.9	1.2	1.1	1.3	0.5	1.3	1.6
Ba	695.3	593.1	965.3	779.0	540.6	643.1	507.8	517.6	423.6	492.9	512.4	189.2	648.6	495.3
La	40.8	32.0	51.2	38.7	43.0	33.0	62.8	42.0	71.9	37.0	86.2	22.8	40.5	14.8
Ce	85.8	63.1	106.2	72.4	122.2	53.0	138.7	74.2	152.6	68.2	180.6	40.3	82.8	30.0
Sm	11.6	10.0	21.4	0.0	12.1	4.1	12.6	7.0	13.5	6.3	13.4	3.5	7.9	4.0
Yb	5.8	2.9	8.0	0.0	8.3	3.8	7.5	4.0	7.9	4.3	7.9	1.6	4.0	1.5
Hf	10.3	5.7	15.0	0.0	17.0	5.2	14.6	6.9	14.6	8.7	13.3	2.6	9.0	2.2
Pb	14.9	8.3	16.2	4.9	9.6	3.7	20.7	12.5	23.4	11.7	24.0	9.1	18.1	10.2
Th	7.2	4.7	5.5	4.6	13.6	4.2	12.2	7.9	13.2	8.3	22.6	6.6	8.6	6.9
U	2.7	1.3	3.0	1.3	4.3	0.6	5.6	3.4	6.1	4.1	7.9	3.5	5.8	1.9

(Wt%)	Partial CIPW norms													
Q	25.59	10.28	23.12	13.49	33.48	1.88	31.06	7.58	31.61	4.03	25.18	6.96	28.41	10.34
C	0.45	0.74	0.46	1.02	0.00	0.00	0.05	0.11	0.03	0.07	0.00	0.01	0.72	2.21
Or	27.68	17.87	30.49	5.81	13.23	12.91	28.38	16.68	28.05	3.06	32.96	2.68	28.83	6.97
Ab	35.12	16.65	33.18	8.88	47.18	12.78	34.37	14.19	34.96	4.58	33.38	2.36	31.92	9.40
An	4.45	4.15	3.90	3.54	0.73	0.59	1.79	3.01	1.48	1.78	3.36	4.90	5.87	5.51
Di	0.50	0.68	0.45	0.60	1.07	1.25	0.42	0.48	0.39	0.44	1.09	0.67	0.41	0.89
Hy	1.42	1.41	0.53	0.54	0.51	1.13	0.81	2.07	0.50	0.78	0.47	0.77	1.35	1.85
Ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mt	0.49	0.86	0.13	0.28	1.92	1.13	1.22	0.97	1.42	1.00	1.24	0.78	1.21	0.64
Il	0.52	0.37	0.55	0.25	0.42	0.15	0.42	0.21	0.39	0.17	0.68	0.22	0.46	0.27

KEY TO UNITS (UAG - Upper Aillik Group   JEA - Jagged Edge assemblage)
1.0 -- (UAG) Undivided volcanic and volcaniclastic rocks   1.3 -- (UAG) Hypabyssal Intrusive Rocks
1.0 (unaltd) -- As above, excluding N/N+K > 0.65 or < 0.3   1.4 -- (JEA) Volcanic and volcaniclastic rock
1.1 -- (UAG) Early sequence of Gower and Ryan (1988)
1.2 -- (UAG) Late sequence of Gower and Ryan (1988)
1.2 (unaltd) -- As above, excluding N/N+K > 0.65 or < 0.3

n1 -- Number of analyses for all elements except those listed below
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf

Table 7.1 (continued)

UNIT	1.5		2.1		2.2		2.3		2.4		2.5		2.6	
n1	4		3		9		6		3		27		22	
n2	1		0		0		0		0		0		0	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	73.54	3.28	54.43	5.46	60.17	3.83	51.25	5.43	55.20	3.22	71.20	2.99	70.10	8.38
TiO2	0.28	0.15	0.69	0.14	0.73	0.10	1.41	0.82	0.71	0.02	0.34	0.11	0.37	0.23
Al2O3	11.90	2.17	13.38	2.76	15.36	1.16	16.78	1.01	15.77	0.64	14.22	1.12	13.80	1.67
Fe2O3	2.38	0.67	2.88	0.96	4.72	1.61	5.71	3.44	3.08	0.77	1.73	0.57	1.25	1.15
FeO	0.62	0.48	4.27	1.33	1.07	1.16	3.63	1.61	4.06	0.60	0.40	0.26	1.25	1.47
MnO	0.07	0.06	0.12	0.03	0.08	0.03	0.13	0.04	0.13	0.03	0.04	0.02	0.07	0.07
MgO	0.28	0.29	9.45	6.59	3.06	2.48	4.59	1.72	5.07	1.41	0.37	0.22	1.43	2.42
CaO	1.85	2.00	5.70	1.85	3.08	1.37	5.64	1.33	6.93	1.33	0.81	0.49	1.87	2.37
Na2O	2.38	1.29	2.90	1.43	3.75	0.75	3.25	0.83	2.92	0.41	4.20	0.91	3.60	0.66
K2O	5.80	0.85	2.92	0.81	4.67	1.53	2.63	0.55	3.31	0.35	5.20	0.90	4.93	1.31
P2O5	0.07	0.06	0.19	0.07	0.22	0.08	0.30	0.15	0.11	0.07	0.04	0.04	0.08	0.08
LOI	0.56	0.11	3.25	0.61	2.98	0.90	4.39	2.67	2.11	0.53	1.13	0.46	0.88	0.46
TOTAL	99.72		100.18		99.89		99.71		99.40		99.68		99.63	
(ppm)														
Li	12.5	10.9												
F	551.3	377.6												
Sc	2.7	0.0												
V	21.8	14.9	141.3	22.6	107.4	37.6	182.8	46.4	182.3	54.7	11.4	6.8	37.2	53.7
Cr	7.0	2.6	682.7	594.5	208.3	273.6	57.3	67.6	114.7	57.5	4.9	0.4	44.2	93.7
Ni	1.0	0.0	274.0	231.0	88.9	97.5	36.3	20.4	46.3	13.5	13.7	5.3	20.9	21.8
Cu	17.3	24.2	58.7	43.8	10.9	19.9	10.5	14.9	4.0	3.5	2.4	1.5	6.0	11.2
Zn	54.3	10.0	54.7	4.2	49.6	20.4	114.8	51.9	66.0	3.5	33.1	12.9	43.2	53.4
Ga	8.8	2.9	12.0	2.7	15.4	2.9	20.0	6.1	16.0	1.0	15.2	2.7	13.9	2.2
Rb	183.5	44.6	74.3	9.5	123.9	45.1	86.8	28.8	92.7	17.8	169.7	40.0	163.7	40.6
Sr	148.8	164.0	407.7	103.9	375.0	150.8	388.7	165.3	499.7	100.0	134.3	96.9	173.9	185.9
Y	56.3	36.4	23.7	5.1	29.9	4.2	29.3	9.7	23.3	2.1	42.9	10.4	31.1	6.0
Zr	509.3	330.4	149.3	79.4	237.1	50.9	177.3	57.2	126.7	51.8	312.7	68.4	178.5	59.7
Nb	21.3	13.6	10.0	2.7	13.4	3.1	10.0	3.3	7.3	3.1	19.7	4.1	18.9	5.4
Mo	2.3	0.5												
Sn	5.0	0.0												
Cs	0.9	0.0												
Ba	721.5	812.0	899.7	328.5	1268.1	189.2	972.8	261.7	1080.3	257.5	983.2	540.1	614.0	551.9
La	54.0	14.7												
Ce	125.5	52.5												
Sm	10.5	0.0												
Yb	6.6	0.0												
Hf	12.0	0.0												
Pb	20.8	4.0	13.3	1.2	13.6	7.1	9.7	4.4	10.3	0.6	20.7	5.8	28.2	15.7
Th	14.3	12.6	4.7	4.7	9.0	5.4	5.5	5.3	1.3	0.6	17.4	6.5	14.0	6.6
U	6.4	3.0	1.0	0.0	2.1	1.8	1.7	1.0	1.0	0.0	3.4	2.0	3.1	2.0
(Wt%)														
Q	34.51	5.73	3.73	3.81	10.65	5.81	6.16	5.22	4.65	4.06	24.94	5.59	25.00	13.18
C	0.21	0.33	0.00	0.00	0.26	0.52	0.66	1.04	0.00	0.00	0.36	0.43	0.31	0.41
Or	34.56	5.12	17.75	4.86	28.44	9.19	16.31	3.59	20.12	2.23	31.15	5.34	29.48	7.69
Ab	20.25	10.95	25.22	12.38	32.69	6.49	28.15	6.48	25.39	3.84	36.08	7.84	30.77	5.66
An	4.13	4.49	15.32	4.00	10.94	4.31	22.80	3.21	20.65	4.36	3.67	2.48	6.18	7.19
Di	0.33	0.62	10.17	6.49	2.84	3.42	3.87	3.60	11.45	2.12	0.19	0.36	2.15	4.02
Hy	0.55	0.81	15.15	6.69	7.01	6.51	6.87	6.35	11.34	2.94	0.88	0.61	2.60	4.31
Ol	0.00	0.00	6.38	11.05	0.00	0.00	3.76	5.83	0.15	0.25	0.00	0.00	0.76	2.70
Mt	1.44	1.19	4.29	1.44	0.88	1.42	5.08	2.16	4.59	1.12	0.48	0.58	1.40	1.65
Il	0.53	0.28	1.35	0.27	1.37	0.24	2.79	1.60	1.38	0.03	0.61	0.24	0.69	0.44

KEY TO UNITS : (JEA - Jagged Edge assemblage, BRG - Bruce River Group)
1.5 -- (JEA) Hypabyssal intrusive rocks
2.1 -- (BRG) Lovermost basalt and andesite
2.2 -- (BRG) Andesite and Trachyte
2.3 -- (BRG) Basalt and andesite (Camel Lake)
2.4 -- (BRG) Basalt and andesite (Pearl Lake)
2.5 -- (BRG) Trachyte and Rhyolite (Sylvia Lake Fm)
2.6 -- (BRG) Undivided (mostly felsic) volcanic rocks

n1 -- Number of analyses for all elements except those listed below
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf
(For analytical details of BRG data, see Ryan, 1984)

7.2.2 General Geochemistry

Summary of Numerical Data

Mean compositions of various volcanic units are listed in Table 7.1. Data for the Bruce River Group are from Ryan (1984), and are subdivided into his six principal units.

The Upper Aillik Group in its type area is subdivided into "early" and "late" components (c.f. Gower and Ryan, 1987), hypabyssal intrusive rocks and unclassified samples (most of these are strongly recrystallized). The Jagged Edge assemblage is similarly subdivided into volcanic or pyroclastic rocks and hypabyssal intrusive rocks.

Major element compositions of all felsic rock types are closely similar. The mean composition of samples from the early Upper Aillik Group (c.f Gower and Ryan, 1987) is sodic (i.e. $Na_2O > K_2O$) compared to other subdivisions. However, this average is based on only 5 samples, and is radically different from representative compositions listed by Gower and Ryan (1987). It is, however, similar to the mean for these units in the Round Pond area reported by MacDougall (1988). There are problems in differentiating recrystallized arenites from rhyolites in the early Upper Aillik Group, and these averages are not neccessarily "igneous" compositions. Undivided Upper Aillik Group rocks are similar in mean composition to the Late Upper Aillik Group and hypabyssal intrusive rocks. "Unaltered" mean compositions (for samples where 0.3 < N/N+K < 0.65) are similar to those for all data. This reflects complementary patterns of Na and K-metasomatism, with total alkali contents remaining approximately constant (see below).

Trace element patterns are broadly similar for all felsic units, but the Jagged Edge assemblage and Bruce

AFGT - Alkali Fsp Granite   MZDR - Monzodiorite   SENT - Syenite
AFQS - Alkali Fsp Quartz Syenite   TNLT - Tonalite   MZGT - Monzogranite
AFST - Alkali Fsp Syenite   QZDR - Quartz Diorite   QZMZ - Quartz Monzonite
GRNT - Granite (s.s.)   DORT - Diorite   MNZN - Monzonite
QSZT - Quartz Syenite   QZGB - Quartz Gabbro   GRDR - Granodiorite
    GBBR - Gabbro   QZMD - Quartz Monzodiorite
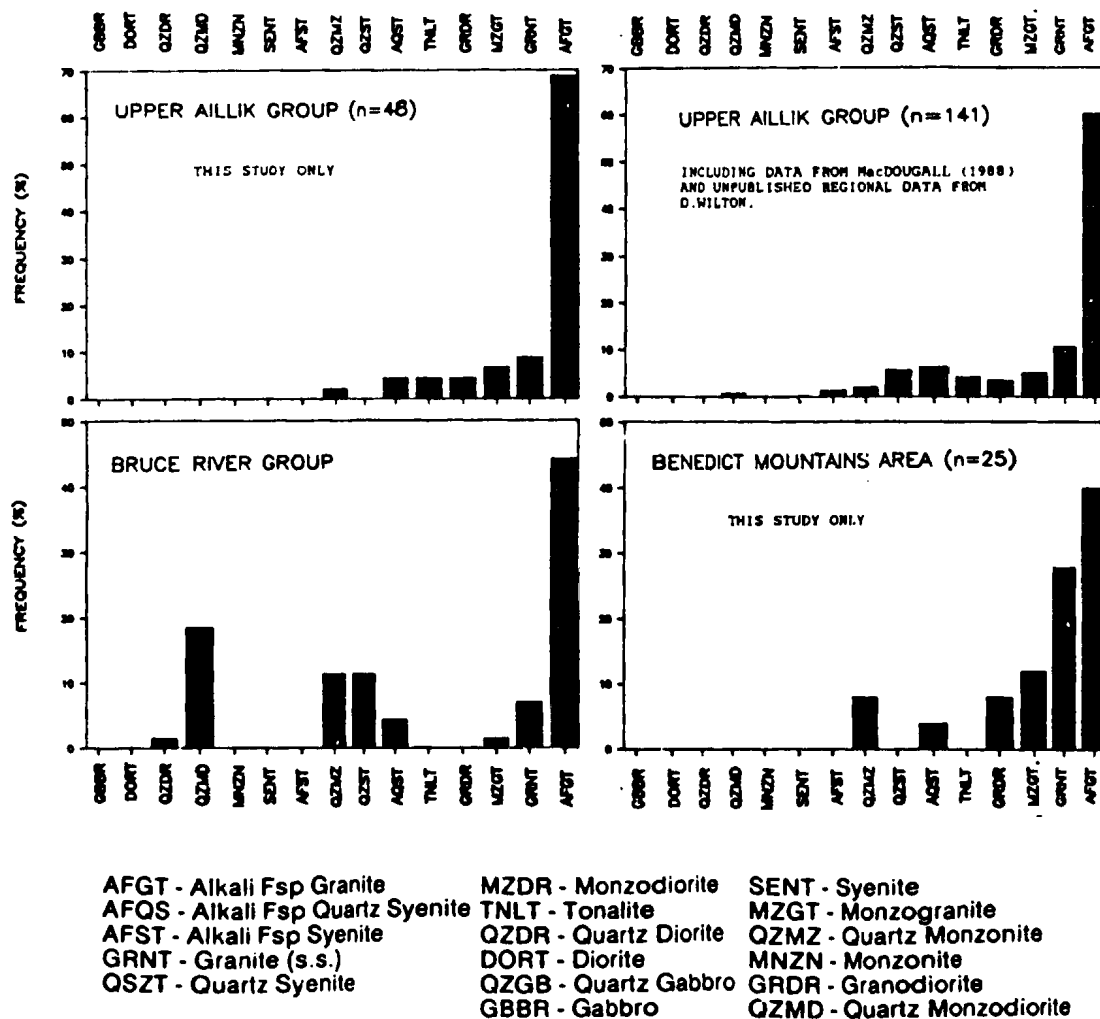
Figure 7.2. Relative abundance of IUGS rock types calculated from normative mineralogy after Streckeisen and LeMaitre (1979). Note that this is based on Barth mesonorms, not the CIPW norms listed in Table 7.2.

River Group display somewhat lower La, Ce, Zr and Y
contents than the Upper Aillik Group. All volcanic
sequences have relatively low fluorine contents.

Abundance and Distribution of Rock Types

Relative abundances of IUGS rock types, expressed as
equivalent plutonic rocks (Figure 7.2) have been calculated
from normative data using the method of Streckeisen and
LeMaitre (1979). It is recognized that sampling is
unstructured compared to that for plutonic suites, and that
these patterns may not be fully representative.

The Upper Aillik Group is dominated by equivalents of
alkali-feldspar granite, with only minor equivalents of
granite, tonalite, monzongranite and granodiorite.
Addition of regional data from D.Wilton (unpublished) and
MacDougall (1988) does not change the distribution of rock
types significantly. Note that mafic volcanic and
tuffaceous rocks were not included in this compilation. The
Jagged Edge assemblage includes a higher proportion of
granite and monzogranite equivalents. If the data of Ryan
(1984) are representative, the Bruce River Group has a
strongly bimodal distribution of rock types.
Alkali-feldspar granite equivalents are dominant, but there
is a lesser population corresponding to quartz
monzodiorite, quartz monzonite and quartz syenite. True
basaltic compositions (i.e. equivalent to normative gabbro)
are absent. Ryan et al. (1987) also note a bimodal SiO_2
distribution in a larger dataset including upublished data
obtained from W.R.Baragar. The Upper Aillik Group has also
been described as bimodal in previous studies (see above)
but, on the basis of map areas, is poorer in mafic
compositions.

7.2.3 Geochemical Trends and Contrasts

Geochemical data are divided into three groups (A, B and C) to avoid clutter in diagrams. The X-axis scales in Harker variation diagrams are expanded for the Bruce River Group to compensate for its greater SiO_2 range. Y axis scales are constant for all figure groups.

Major Element Patterns

Major element oxides show expected trends. All except Na_2O and K_2O have strong negative correlations with SiO_2 (e.g. TiO_2 and FeO total; Figure 7.3). K+N/A (Agpaitic Index) values (Figure 7.3) are mostly > 0.9 in the Upper Aillik Group, and several samples are peralkaline. There are no peralkaline rocks in the Jagged Edge assemblage or Bruce River Group, which show lower K+N/A at equivalent SiO_2 contents. The Upper Aillik Group includes a few peraluminous samples (Figure 7.3), but most samples have A/C+N+K < 1.0. In contrast, ca. 50% of the Jagged Edge assemblage and Bruce River Group samples are peraluminous above 65% SiO_2.

Alkali disturbance in the Upper Aillik Group is indicated by variation of N/N+K ratios versus total alkali content (Figure 7.4). As noted previously (Evans, 1980; MacDougall, 1988), many Upper Aillik Group volcanic rocks lie outside the "igneous spectrum" of Hughes (1973). The Jagged Edge assemblage and Bruce River Group show less evidence of alkali disturbance.

AFM projections (Figure 7.5) are totally useless in unit discrimination. CNK projections (Figure 7.5) illustrate the alkali disturbance in the Upper Aillik Group well. Alkali- SiO_2 plots (Figure 7.5) indicate that all volcanic suites are subalkaline, at least in terms of their present compositions.
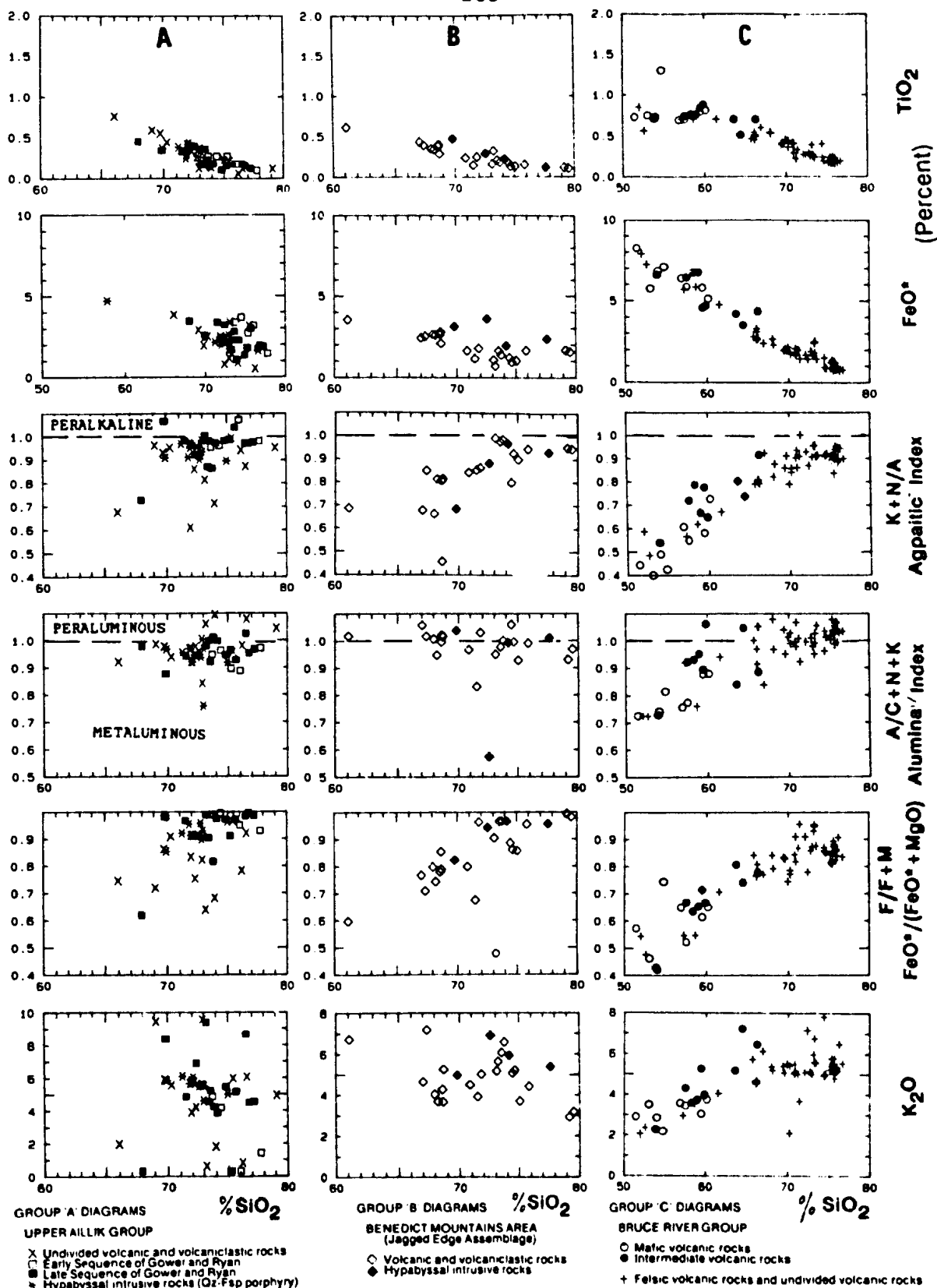
Figure 7.3. Variation of selected major elements and derived parameters in volcanic assemblages. See text for discussion.
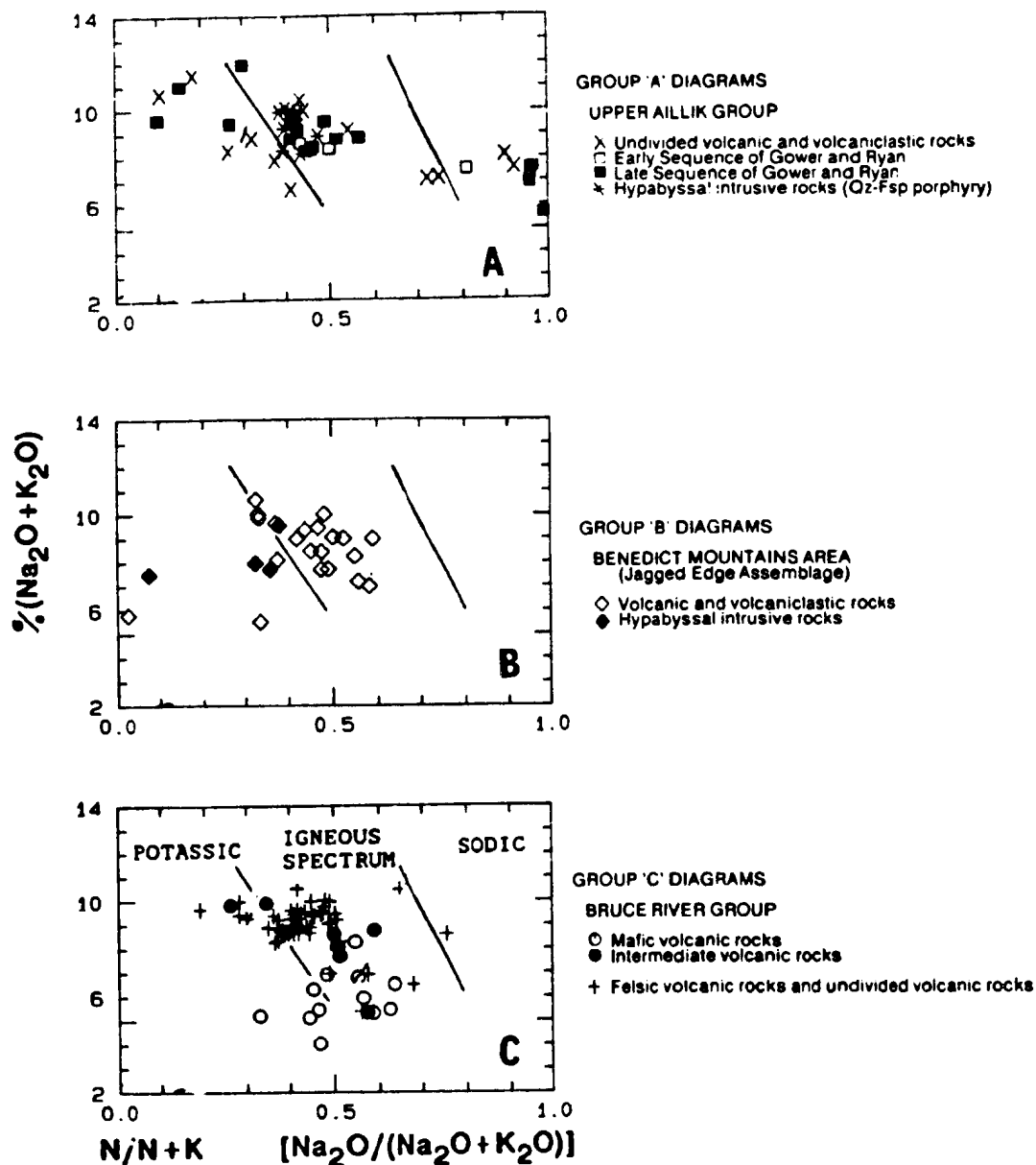
Figure 7.4. Variation in N/N+K (Na₂O/(Na₂O+K₂O)) and total alkali content in volcanic assemblages in relation to the igneous spectrum (after Hughes, 1973).
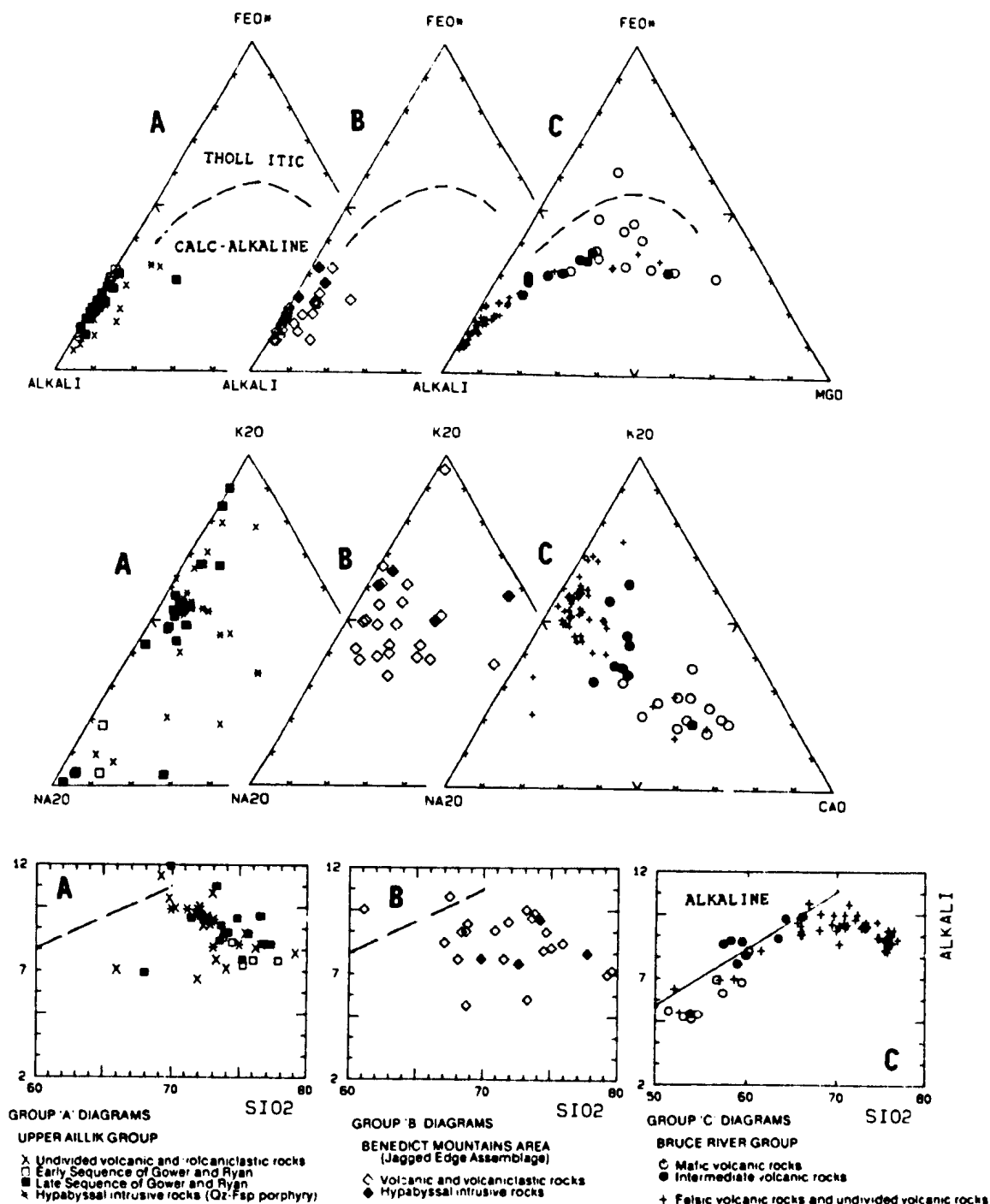
Figure 7.5 Ternary AFM and CNK projections, and binary SiO₂-Alkali projections for volcanic assemblages. See text for discussion.

Normative Compositions

The Upper Aillik Group has a scattered distribution in the Q-Ab-Or-An system (Figure 7.6), due to alkali disturbance. The Bruce River Group has the most coherent distribution, but all volcanic sequences are scattered compared to plutonic suites described in preceding chapters (Figure 3.6, p.81; Figure 4.5, p.136; Figure 5.13, p.208). The felsic volcanic rocks of all sequences occupy the general area of ternary minima in the granite system (James and Hamilton, 1969).

Trace Element Patterns

Octahedrally Co-ordinated Cation (OCC) Elements :
Cu, Ni, Sc, Cr and V) have closely similar, negative trends against SiO_2 and do not discriminate sequences (e.g. V; Figure 7.7). Mafic volcanic rocks of the Bruce River Group show the highest levels of these elements.

Low-Field Strength (LFS) Trace Elements : Incompatible LFS elements (e.g. Rb and U; Figure 7.7) have similar average abundances in all sequences (Table 7.1), but exhibit considerable scatter in the Upper Aillik Group, probably in response to alkali metasomatism. Volcanic rocks show much greater scatter than hypabyssal intrusive rocks.

Compatible LFS elements (e.g. Ba and Sr; Figure 7.7) show negative trends against SiO_2, but some high-SiO_2 Upper Aillik Group volcanic rocks show suspiciously high Sr and Ba. The convex-upward Ba trend in the Bruce River Group resembles patterns in compositionally expanded plutonic suites such as the Labradorian Mount Benedict Intrusive Suite (Chapter 5), but the felsic compositions do not show strong incompatible element enrichment.
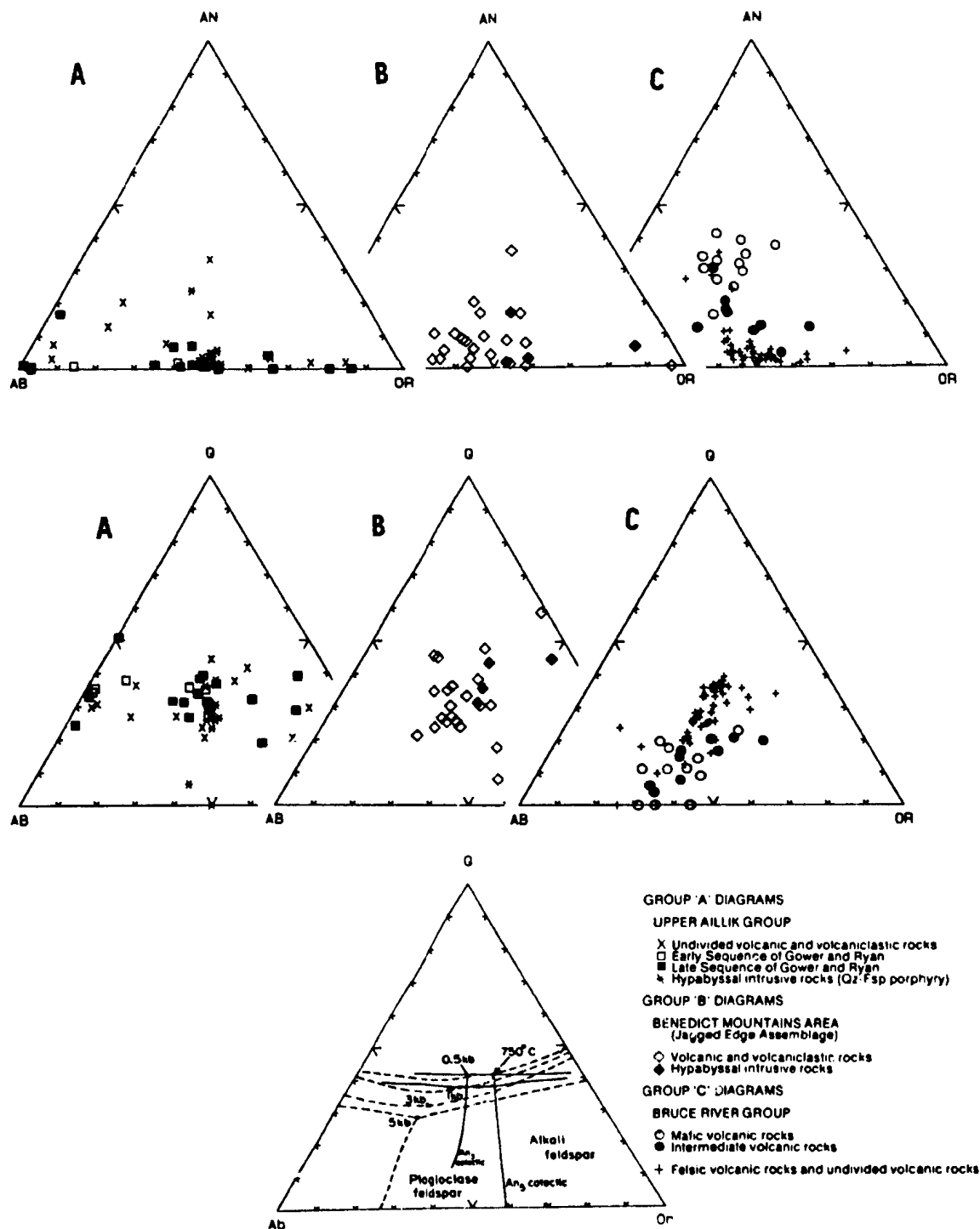
Figure 7.6. Composition of volcanic assemblages in the quartz - albite - anorthite - orthoclase quaternary system. All norms are CIPW. See text for discussion.

High Field Strength (HFS) Elements : Zr and Nb (Figure 7.8) are enriched in the Upper Aillik Group relative to the Bruce River Group and Jagged Edge assemblage volcanics. The volcanic rocks of the Upper Aillik Group show greater variation than hypabyssal intrusive rocks. Upper Aillik Group patterns closely resemble those of syn- and post-tectonic Makkovikian granites, in particular the Kennedy Mountain, Strawberry and Lanceground Intrusive Suites, whose distribution is indicated by dashed boxes in Figures 7.7 and 7.8.

Rare Earth Elements (REE) : Ce and Y (Figure 7.8) are enriched in the Upper Aillik Group relative to the Jagged Edge assemblage. Their distribution resembles those of HFS elements described above.

Indeterminate Trace Elements : Fluorine (Figure 7.7) is generally low (< 700 ppm) in the Upper Aillik Group and Jagged Edge assemblage, but locally ranges up to 1500 ppm. There appears to be a negative trend against SiO_2 in the latter sequence. Hypabyssal intrusive rocks have higher F contents than volcanic rocks, but not to the levels of some Makkovikian granites. Zn (Figure 7.7) has an inverse trend against SiO_2 in the Bruce River Group (Figure 7.8), but is scattered in the Upper Aillik Group, where Zn contents are anomalously high above 70% SiO_2.

Trace Element Variation in Response to Disturbance of Major Element Compositions

Strong negative correlations are present between LFS trace elements (e.g. Rb, U, Pb, also Li) and N/N+K ratios (Figure 7.9), indicating that soda enrichment is
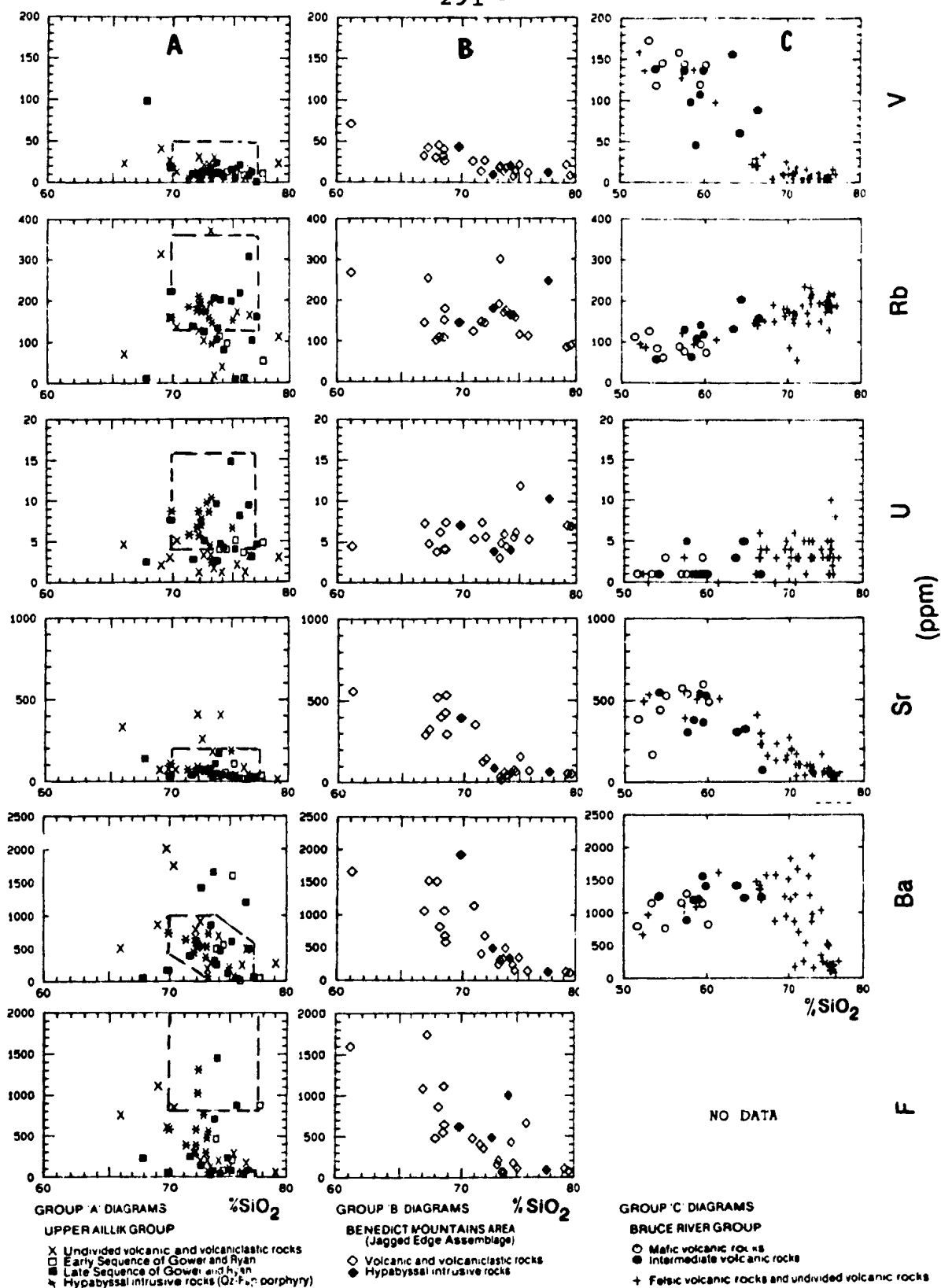
Figure 7.7. V, Rb, U, Sr, Ba and F versus SiO$_2$ in volcanic assemblages. See text for discussion.
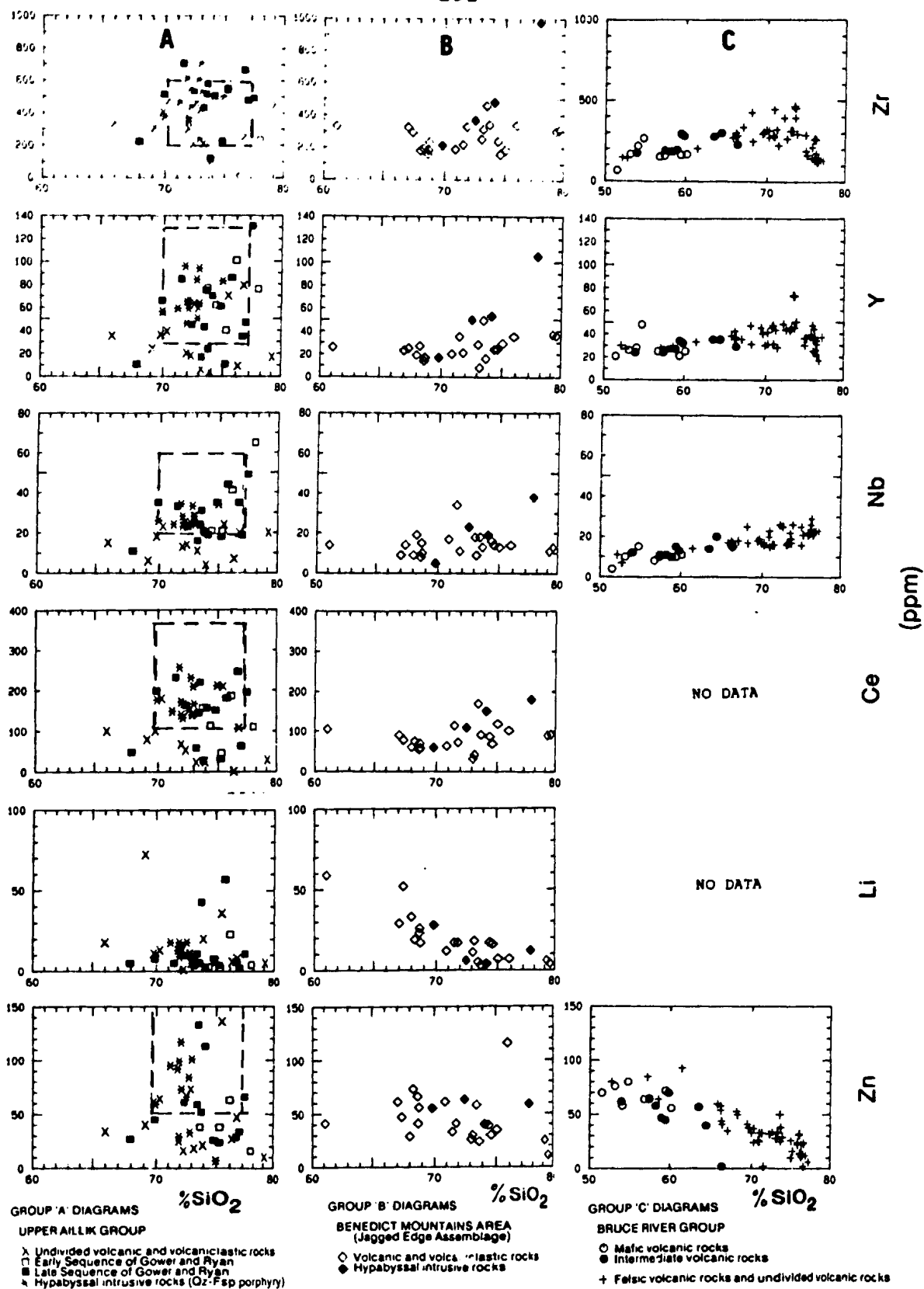
Figure 7.8. Zr, Nb, Y, Ce, Li and Zn versus SiO$_2$ in volcanic assemblages. See text for discussion.

accompanied by depletion of these elements, and potash enrichment by an increase. Other trace elements (e.g. Zr, Y and Nb) are uncorrelated with N/N+K, and fluorine is depleted in both sodic and potassic variants. This indicates that the higher Zr, Y and Nb in the Upper Aillik Group (compared to other sequences) is a primary feature, and unrelated to metasomatic effects. The patterns of alkali disturbance, and trace element behaviour, are remarkably similar to those documented from the plutonic rocks of the Kennedy Mountain Intrusive Suite (Chapter 3; Figure 3.9, p.86).

Trace Element Ratios

K/Rb ratios (Figure 7.10) are constant in all three groups of volcanic rocks at ca. 400 - 500, but the Upper Aillik Group includes a disturbed population with very low K/Rb.

Rb/Sr ratios (Figure 7.10) range from less than 0.1 to greater than 10 in all three suites, and show great variation in the Upper Aillik Group; this variation is almost certainly related to alkali metasomatism. In contrast, the Bruce River Group has a well-defined curvilinear trend, which becomes flat-lying in high-silica rocks.

Ba/Sr ratios (Figure 7.10) are obviously disturbed in the Upper Aillik Group, but show a consistent trend (Ba/Sr= 2 to 4) in the Jagged Edge assemblage. The Bruce River Group has a curvilinear trend. La_N/Y_N ratios are consistent (ca.10 to ??) in all groups, but the absolute abundances differ (see Figure 7.8 also)

Bruce River Group trends are consistent with removal of plagioclase (± mafic minerals) from less evolved

- 294 -
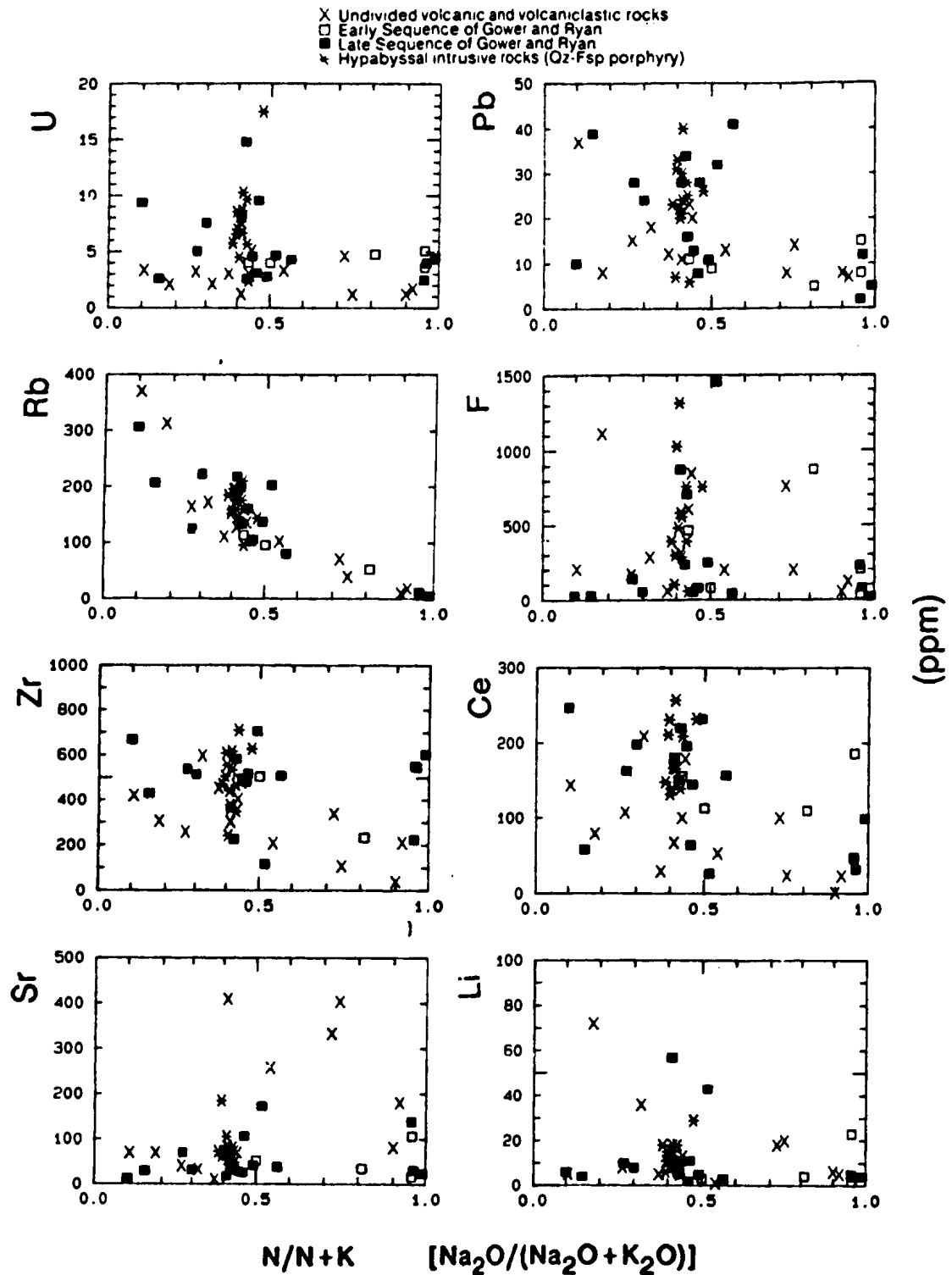
Figure 7.9. Variation of selected trace elements against N/N+K (Na₂O/(Na₂O+K₂O)) for the Upper Aillik Group.
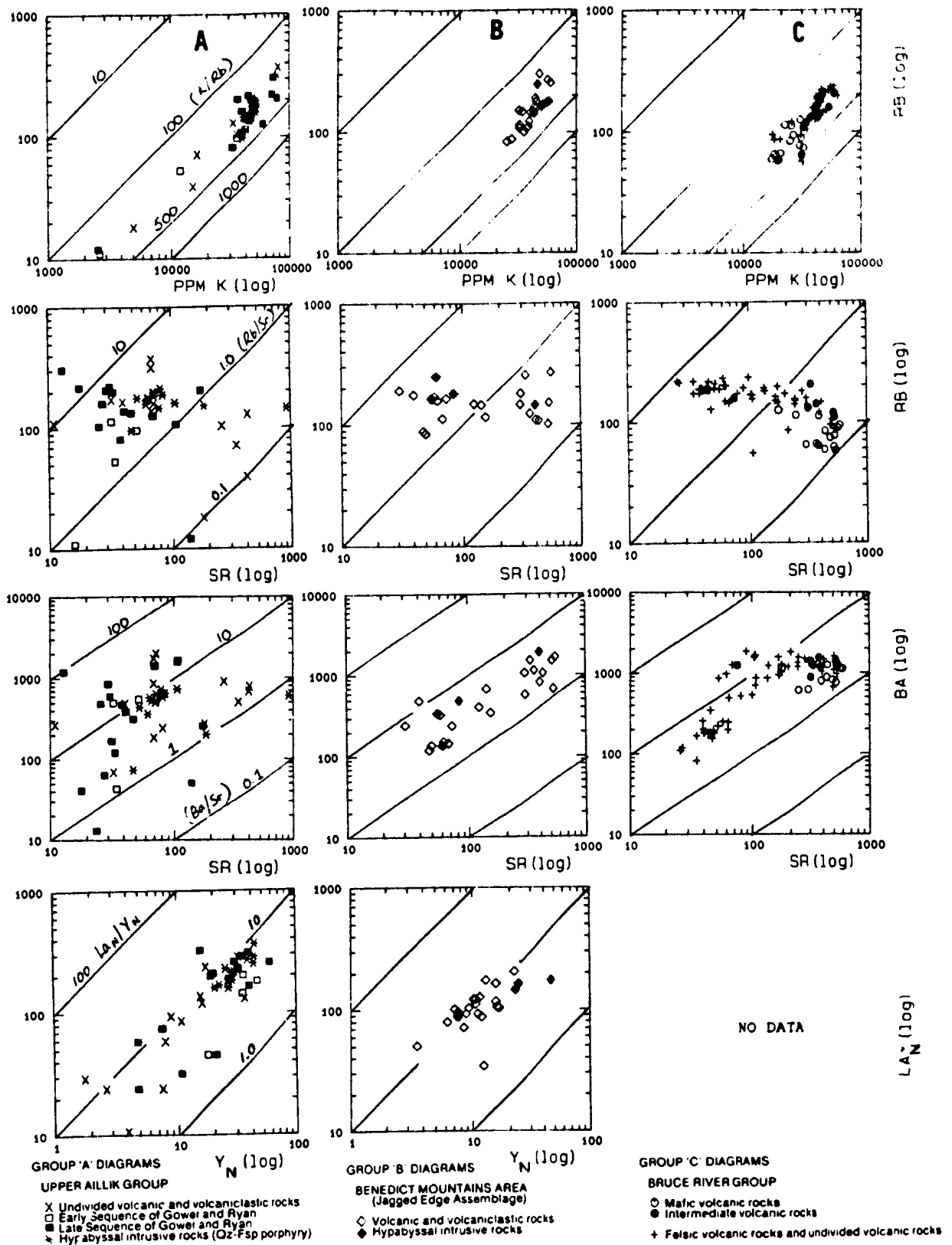
Figure 7.10. Variation in the trace element ratios K/Rb, Rb/Sr, Ba/Sr and La$_N$/Y$_N$ in volcanic assemblages. See text for discussion.
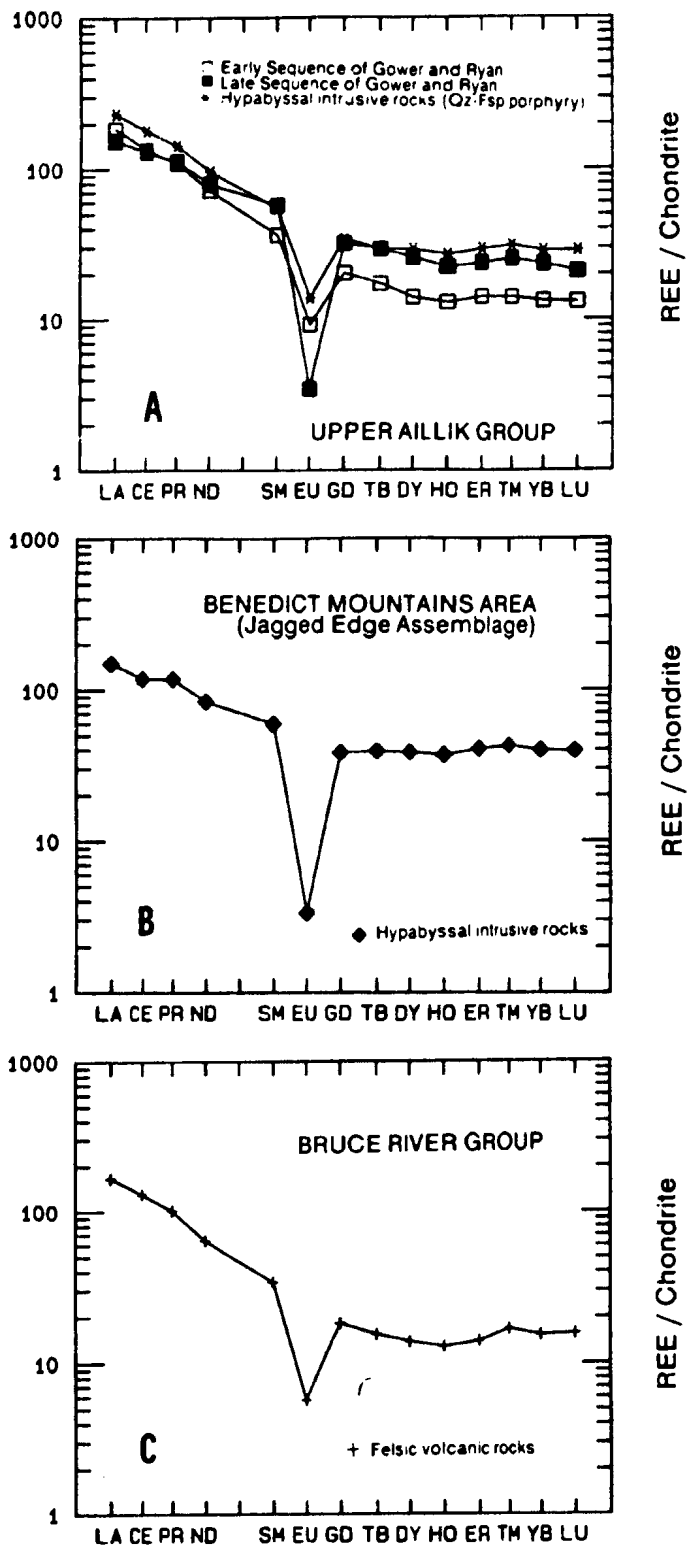
Figure 7.11. Rare Earth element (REE) patterns samples from volcanic assemblages. Values are normalized to chondritic values (listed in Appendix C).

compositions, and increased K-feldspar fractionation in more siliceous magmas. Jagged Edge assemblage trends are also consistent with feldspar fractionation. No conclusion can be drawn from Upper Aillik Group data.

Rare-Earth Element (REE) Patterns

Five samples were analyzed for the complete REE spectrum (Figure 7.11); samples from the Upper Aillik and Bruce River Group are from fresh, unaltered localities dated by Scharer et al. (1988). All have closely similar patterns, which are similar to those of Makkovikian and some Labradorian granites (Figures 3.11, p.91; 4.9, p.145; 5.17, p.216).

This similarity is not, however, an indication of a direct relationship between the volcanic sequences, as the White Bear Mountain porphyry is 50 Ma younger than other Upper Aillik volcanic rocks and 15C Ma older than the Bruce River Group (Schärer et al., 1988). Patterns are similar to those previously reported by White and Martin (1980), Gower and Ryan (1987) and Ryan et al.(1987) from the Upper Aillik and Bruce River Groups respectively.

7.3 SUMMARY and DISCUSSION

Correspondance of Volcanic and Plutonic Assemblages

Table 7.2 compares the average compositions of volcanic and hypabyssal rocks of the Upper Aillik Group and Jagged Edge assemblage to granitoid plutonic units that have similar major element compositions.

With the exception of fluorine, trace element patterns for the Upper Aillik Group are very close to those of the Kennedy Mountain, Strawberry and Lanceground Intrusive

Table 7.2. A comparison of average compositions of volcanic
assemblages to Makkovikian and Labradorian plutonic units of
similar major element composition.

UNIT	1.0		1.1		1.2		1.3		11		23-26		27-29	
n1	13		5		16		14		97		197		82	
n2	3		5		15		13		22		142		66	
(wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO2	72.81	3.54	75.42	1.56	74.26	3.29	71.27	3.99	73.58	2.98	71.29	4.71	72.12	2.93
TiO2	0.32	0.22	0.22	0.08	0.23	0.11	0.36	0.11	0.29	0.19	0.31	0.27	0.32	0.19
Al2O3	13.61	1.59	11.75	0.24	12.49	1.35	13.61	1.80	12.67	1.15	13.68	1.55	13.22	1.34
Fe2O3	1.47	1.10	1.86	0.78	1.65	0.56	1.82	0.88	1.24	0.70	1.05	0.74	1.21	0.57
FeO	0.60	0.62	1.20	0.50	0.77	0.67	0.79	0.46	1.39	1.17	1.68	1.47	1.44	0.87
MnO	0.04	0.02	0.05	0.02	0.04	0.02	0.06	0.02	0.06	0.02	0.06	0.06	0.06	0.04
MgO	0.44	0.40	0.07	0.06	0.23	0.52	0.28	0.28	0.19	0.25	0.36	0.50	0.18	0.17
CaO	1.09	0.93	0.52	0.22	0.59	0.59	1.19	1.13	0.82	0.56	1.14	1.04	0.88	0.47
Na2O	4.02	1.90	5.62	1.60	4.08	1.62	3.90	0.28	4.00	0.48	4.09	0.86	3.97	0.61
K2O	4.67	2.89	2.22	2.17	4.77	2.81	5.52	0.45	4.85	0.64	5.12	1.10	5.47	0.90
P2O5	0.07	0.06	0.02	0.00	0.03	0.03	0.04	0.04	0.05	0.05	0.07	0.09	0.04	0.04
LOI	0.69	0.38	0.46	0.28	0.44	0.22	0.57	0.31	0.45	0.22	0.67	0.37	0.53	0.20
TOTAL	99.83		99.41		99.58		99.41		99.57		99.52		99.44	
(ppm)	Trace Elements													
Li	16.5	19.0	7.4	8.8	11.7	15.4	13.1	6.2	14.9	11.7	25.0	23.5	13.9	11.7
F	378.5	339.8	331.8	346.3	272.0	401.2	541.1	343.2	1029.9	803.8	1420.0	1141	1244.6	935.7
Sc	1.7	0.9	1.8	1.4	2.2	1.9	4.8	2.7	1.4	0.9	3.1	4.1	3.8	5.3
V	21.1	9.6	11.4	1.7	18.4	22.1	13.3	9.9	15.9	13.4	23.3	29.2	12.8	7.7
Cr	6.0	10.4	7.2	11.8	7.6	8.2	5.9	3.7	4.7	3.8	5.1	6.5	3.7	2.9
Ni	2.5	3.3	5.4	9.8	1.4	1.5	2.0	2.8	1.3	1.2	2.2	3.9	1.5	1.8
Cu	4.2	3.4	14.6	24.3	4.7	3.7	6.9	8.8	3.9	3.9	9.3	38.4	6.0	9.2
Zn	44.0	34.1	66.8	64.9	86.1	81.0	77.8	41.7	77.1	29.9	75.1	69.6	89.6	59.6
Ga	12.6	4.3	24.2	6.7	15.4	6.9	11.5	6.7	16.5	6.8	16.9	8.6	21.4	10.0
Rb	138.1	105.8	56.4	48.2	139.4	86.2	168.2	28.8	153.5	47.1	178.4	65.0	172.5	44.1
Sr	156.4	144.7	48.8	35.1	53.4	46.3	140.9	226.4	60.8	77.5	111.7	130.2	61.2	65.8
Y	32.0	24.3	71.2	22.4	54.7	32.2	69.9	17.1	70.9	28.9	55.4	43.8	74.4	32.8
Zr	317.3	155.6	593.6	354.3	529.8	264.6	490.4	129.4	387.0	151.8	491.5	558.5	675.7	439.3
Nb	15.5	7.1	33.8	19.5	27.8	10.7	29.2	7.6	27.9	14.0	26.0	21.0	29.3	11.1
Mo	2.9	1.2	14.0	22.5	7.4	15.2	2.8	1.1	3.7	1.9	4.3	7.7	4.3	2.3
Sn	3.0	3.5	9.2	9.4	5.2	2.8	6.4	2.9	3.5	2.5	5.8	9.9	4.0	2.6
Cs	1.0	0.9	0.5	0.0	1.0	0.9	1.3	0.5	0.6	0.4	1.2	1.0	1.1	0.7
Ba	695.3	593.1	540.6	643.1	507.8	517.6	512.4	189.2	453.1	411.7	501.9	382.6	329.6	260.1
La	40.8	32.0	43.0	33.0	62.8	42.0	86.2	22.8	76.6	33.3	90.7	111.7	122.8	62.6
Ce	85.8	63.1	122.2	53.0	138.7	74.2	180.6	40.3	158.7	65.7	178.7	197.0	247.2	121.1
Sm	11.6	10.0	12.1	4.1	12.6	7.0	13.4	3.5	12.6	3.5	13.1	10.4	20.8	9.8
Yb	5.8	2.9	8.3	3.8	7.5	4.0	7.9	1.6	7.7	3.2	6.6	4.7	8.8	4.3
Hf	10.3	5.7	17.0	5.2	14.6	6.9	13.3	2.6	12.1	3.1	13.3	13.3	19.1	10.3
Pb	14.9	8.3	9.6	3.7	20.7	12.5	24.0	9.1	20.3	10.4	37.3	205.3	24.5	13.5
Th	7.2	4.7	13.6	4.2	12.2	7.9	22.6	6.6	15.2	9.6	18.3	20.5	18.9	8.0
U	2.7	1.3	4.3	0.6	5.6	3.4	7.9	3.5	4.7	3.0	5.8	7.0	5.5	2.3
(wt%)	Partial CIPW norms													
Q	25.59	10.28	33.48	1.88	31.06	7.58	25.18	6.96	29.80	6.01	24.90	9.23	26.22	7.51
C	0.45	0.74	0.00	0.00	0.05	0.11	0.00	0.01	0.02	0.06	0.12	0.23	0.10	0.70
Or	27.68	17.87	13.23	12.91	28.38	16.68	32.96	2.68	28.89	3.89	30.38	5.96	32.64	5.34
Ab	35.12	16.65	47.18	12.78	34.37	14.19	33.38	2.36	34.11	4.02	34.90	7.35	33.79	5.15
An	4.45	4.15	0.73	0.59	1.79	3.01	3.36	4.90	2.30	2.27	3.66	2.94	1.90	1.64
Di	0.50	0.68	1.07	1.25	0.42	0.48	1.09	0.67	1.08	0.87	1.28	2.82	1.62	1.35
Hy	1.42	1.41	0.51	1.13	0.81	2.07	0.47	0.77	1.22	2.00	2.15	2.26	0.96	1.05
Ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.26	0.00	0.00
Mt	0.49	0.86	1.92	1.13	1.22	0.97	1.24	0.78	1.58	0.75	1.38	1.00	1.63	0.77
Il	0.52	0.37	0.42	0.15	0.42	0.21	0.68	0.22	0.54	0.36	0.61	0.52	0.62	0.36

KEY TO UNITS (UAG -- Upper Aillik Group)
1.0 -- (UAG) Undivided volcanic and volcaniclastic rocks
1.1 -- (UAG) Early sequence of Gower and Ryan (1988)
1.2 -- (UAG) Late sequence of Gower and Ryan (1988)
1.3 -- (UAG) Hypabyssal intrusive rocks

11 -- Kennedy Mountain Intrusive Suite
23-26 -- Strawberry Intrusive Suite
27-29 -- Lanceground Intrusive Suite

n1 -- Number of analyses for all elements except those listed below
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf

Table 7.2 (continued)

UNIT	29		WBM		1.4		45		46-47		44		48	
n1	41		11		21		70		34		67		49	
n2	31		11		6		57		29		39		11	
(Wt%)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SiO_2	72.84	2.75	72.28	1.25	71.62	4.37	73.50	4.42	73.24	3.22	70.69	3.31	68.54	4.42
TiO_2	0.30	0.11	0.35	0.06	0.26	0.13	0.14	0.12	0.15	0.11	0.30	0.18	0.44	0.20
Al_2O_3	12.99	1.34	13.32	0.55	14.15	2.08	13.49	1.18	13.98	1.49	14.39	1.06	14.98	1.62
Fe_2O_3	1.07	0.39	1.57	0.33	1.28	0.55	1.08	3.23	0.61	0.45	0.97	0.40	1.20	0.61
FeO	1.35	0.68	0.73	0.33	0.70	0.51	0.70	1.56	0.62	0.31	1.09	0.66	1.87	1.01
MnO	0.06	0.03	0.06	0.02	0.05	0.02	0.05	0.04	0.04	0.01	0.05	0.02	0.06	0.03
MgO	0.37	0.15	0.21	0.09	0.50	0.55	0.21	0.24	0.18	0.13	0.38	0.27	0.86	0.54
CaO	0.82	0.42	0.81	0.25	1.40	1.13	0.76	0.44	0.78	0.36	0.97	0.49	2.04	1.02
Na_2O	3.92	0.66	3.90	0.27	3.72	1.10	4.26	1.07	4.27	1.11	4.28	0.43	3.89	0.55
K_2O	5.42	0.67	5.67	0.30	4.81	1.17	4.72	1.22	4.98	0.87	5.58	0.51	4.70	0.62
P_2O_5	0.04	0.02	0.04	0.02	0.06	0.04	0.03	0.03	0.02	0.03	0.05	0.06	0.15	0.09
LOI	0.50	0.18	0.46	0.09	0.95	0.72	0.58	0.27	0.50	0.13	0.75	0.11	0.77	0.24
TOTAL	99.48		99.48		99.49		99.48		99.37		99.50		99.50	
(ppm)														
Li	14.6	15.2	12.5	4.2	19.0	14.7	20.5	13.6	20.7	19.8	25.3	11.0	25.7	12.5
F	1084.7	763.1	588.6	340.5	540.7	491.0	511.7	436.6	177.7	120.6	1240.5	617.4	679.1	257.1
Sc	3.2	1.7	4.5	1.0	3.4	1.4	1.4	1.2	1.9	1.2	2.9	1.7	6.8	2.4
V	13.8	7.4	11.5	6.3	25.8	14.8	17.4	18.1	14.6	6.8	23.1	13.1	44.6	30.2
Cr	3.8	3.3	5.3	3.0	19.0	55.3	4.0	6.4	3.5	3.8	6.5	3.8	6.5	7.0
Ni	1.8	2.4	1.4	1.2	5.3	14.9	1.4	1.3	1.7	2.1	1.9	1.7	2.1	3.0
Cu	4.7	3.5	8.2	9.6	6.9	5.1	9.2	20.2	3.8	3.7	10.1	8.8	9.1	18.7
Zn	82.8	59.0	69.4	34.6	44.9	22.9	34.9	30.5	28.8	10.9	39.9	14.0	46.9	21.4
Ga	16.2	7.3	8.7	1.0	7.8	1.7	12.0	6.6	11.7	5.8	8.6	2.1	12.8	4.1
Rb	167.1	52.5	176.3	20.4	156.3	58.2	181.7	71.7	191.1	68.2	315.3	81.3	140.5	38.7
Sr	60.0	68.8	86.5	34.8	216.6	187.0	134.5	210.4	87.1	75.8	126.8	108.3	277.7	154.8
Y	75.5	29.3	63.1	11.8	25.2	9.4	26.5	23.0	25.3	20.2	27.8	7.6	28.2	10.2
Zr	560.7	280.9	446.5	106.6	262.5	78.8	160.1	99.3	185.6	172.3	345.0	140.0	240.0	83.8
Nb	29.2	10.1	26.8	3.7	14.2	5.6	17.2	8.5	20.8	13.6	29.0	8.6	13.6	4.4
Mo	3.6	1.5	2.6	0.9	2.6	0.9	84.5	578.7	28.1	142.9	4.3	2.7	3.2	1.2
Sn	4.2	2.8	5.7	2.2	2.3	1.4	2.9	2.3	2.4	2.1	7.2	4.2	3.9	3.3
Cs	1.1	0.7	1.3	0.6	1.3	1.6	2.2	2.1	1.9	1.3	9.0	4.3	4.1	1.8
Ba	308.1	244.0	550.1	155.9	648.6	495.3	391.2	360.5	519.0	675.5	381.9	352.6	961.5	542.3
La	104.7	36.4	78.8	17.4	40.5	14.8	22.1	21.4	30.9	22.3	56.3	22.9	50.6	14.8
Ce	211.9	71.6	166.4	30.9	82.8	30.0	45.4	43.8	63.2	45.7	114.0	43.7	100.1	28.5
Sm	18.0	6.6	12.5	2.9	7.9	4.0	4.4	4.0	4.2	1.9	6.9	1.7	9.3	3.0
Yb	8.5	2.9	7.5	1.1	4.0	1.5	3.9	3.6	2.8	0.6	4.5	0.9	2.5	0.0
Hf	16.8	7.0	12.6	2.1	9.0	2.2	5.6	3.0	5.6	1.5	9.9	3.1	12.5	21.1
Pb	24.7	12.0	25.5	8.6	18.1	10.2	22.6	9.2	26.8	11.5	23.4	8.0	16.8	8.1
Th	22.3	7.3	21.5	4.4	8.6	6.9	13.6	8.5	19.1	9.2	37.5	13.8	14.8	7.3
U	6.3	2.4	7.6	1.8	5.8	1.9	6.0	5.1	7.4	5.0	10.4	4.4	4.0	2.4
(Wt%)														
Q	27.49	7.01	26.50	3.51	28.41	10.34	28.99	5.57	26.82	9.65	22.13	7.27	22.14	8.29
C	0.01	0.05	0.01	0.02	0.72	2.21	0.25	0.24	0.26	0.21	0.12	0.24	0.26	0.36
Or	32.33	3.97	33.83	1.81	28.83	6.97	27.82	7.14	29.78	5.21	33.36	3.06	28.14	3.71
Ab	33.46	5.51	33.32	2.32	31.92	9.40	36.63	8.56	36.39	9.20	36.65	3.68	33.29	4.70
An	1.84	1.57	2.11	1.03	5.87	5.51	3.22	1.70	3.61	1.64	3.30	1.78	8.95	4.23
Di	1.50	1.17	0.89	0.38	0.41	0.89	0.25	0.72	0.16	0.41	0.79	0.82	0.49	0.74
Hy	0.92	0.89	0.27	0.55	1.35	1.85	0.86	0.99	0.87	0.62	1.41	1.11	3.77	2.10
Ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mt	1.50	0.57	1.24	0.69	1.21	0.64	1.29	4.96	0.82	0.46	1.36	0.59	1.76	0.90
Il	0.57	0.20	0.67	0.11	0.46	0.27	0.26	0.22	0.30	0.22	0.58	0.34	0.85	0.38

KEY TO UNITS

29 -- (Lanceground Intrusive Suite) Tarun Granite
WBM -- (UAG) White Bear Mountain porphyry body
1.4 -- (JEA) Volcanic and volcaniclastic rocks
45 -- Monkey Hill Intrusive Suite

46-47 -- Witchdoctor and Burnt Lake Granites
44 -- Mount Benedict Intrusive Suite (granitic unit)
48 -- Otter Lake - Walker Lake Granitoid

n1 -- Number of analyses for all elements except those listed below
n2 -- Number of analyses for Sc, Sn, Cs, Sm, Yb and Hf

Suites (see also Figures 7.7 and 7.8). They also resemble
patterns from the post-tectonic Makkovikian Big River
Granite (not listed). High Zn, Zr, Y and Nb contents are
characteristic of all, but the plutonic rocks have higher
REE abundances. Hypabyssal intrusive rocks show tne closest
similarity (including high fluorine); this is particularly
so for the White Bear Mountain porphyry and the spatially
associated Tarun granite (Table 7.2). Differences in
fluorine content between volcanic and plutonic associations
are to be expected, as volatile components would be lost in
extrusive environments. The HFS element and REE patterns
for the Upper Aillik Group are dissimilar to those of most
Labradorian plutonic rocks of equivalent major element
composition, although Zr contents are similar to parts of
the Mount Benedict Intrusive Suite. LFS element patterns of
all units are broadly similar; however, the Upper Aillik
Group shows great scatter, and generally higher Sr contents
than most plutonic rocks.

The close compositional similarity between the Upper
Aillik Group and Makkovikian high-silica granites is
consistent with, but not definitive of, a genetic link
between them. In the case of younger components of the
former, geochronological data (Loveridge et al., 1987;
Scharer et al., 1988; Gandhi et al., 1988; Krogh et al., in
prep.) indicate that they are of essentially the same age.
However, the Upper Aillik Group also includes volcanic
rocks of ca. 1850-1860 Ma age (Schärer et al., 1988); for
which there are, at present, no recognized plutonic
equivalents. The oldest syn-tectonic Makkovikian granitoid
is of ca. 1840 Ma age (Deus Cape Granitoid, Krogh et al.,
in prep.). It appears that, although the Upper Aillik Group
spans the time-period represented by compositionally

similar plutonic suites, it also includes older episodes of
volcanism that show closely similar characteristics.
Similarly, the younger (ca. 1760 Ma) post-tectonic plutonic
rocks of the Strawberry Suite lie outside the known period
of Upper Aillik Group volcanism.

Geochemical Disturbance in Upper Aillik Group Volcanic Rocks

Upper Aillik Group data collected in this study show
clear evidence of soda and potash metasomatism. As sampling
was conducted without reference to mineralization, this
suggests that disturbance is a regional feature of the
Upper Aillik Group, and not restricted to mineralized
areas. However, as data in this study is somewhat biased
towards areas near intrusive contacts, it could also be
argued that this disturbance is linked to plutonic rocks.
Hypabyssal intrusive rocks within the Upper Aillik Group,
however, do not have disturbed compositions.

There is a striking similarity between these patterns
and those identified in the foliated granites of the
Kennedy Mountain Intrusive Suite (Chapter 3). As previously
discussed (3.3), if these are indeed manifestations of the
same event, it indicates post-volcanic, rather than
syn-volcanic metasomatism with respect to extrusion of the
Upper Aillik Group. The strong compositional similarity
between the Upper Aillik Group and the Kennedy Mountain
Suite (Table 7.2; Figures 7.7; 7.8) may indicate that they
are in part equivalent. This is, however, difficult to
prove without precise dates and evaluation of the
proportions of ca. 1850 and 1800 Ma volcanism in the Upper
Aillik Group. It should also be noted that there is also

some minor alkali disturbance in the post-tectonic Cape
Strawberry Granite and the Labradorian Monkey Hill
Intrusive Suite (Chapters 4 and 5). Alkali-metasomatism is
probably a general feature of high-silica granitoid suites,
but was obviously of greatest intensity in the Upper Aillik
Group and Kennedy Mountain Suite.

Contrasts Between Makkovikian and Labradorian Volcanic Sequences

Geochemical contrasts between Makkovikian and
Labradorian plutonic assemblages are subtle (chapters 3,4
and 5), and their compositions overlap. The differences
between the Upper Aillik Group and Bruce River Group are,
however, analogous to contrasts previously noted between
their plutonic equivalents.

Specifically, The Bruce River Group evolves to
peraluminous compositions, and shows generally lower levels
of HFS elements and REE than the Upper Aillik Group, which
evolves instead to "borderline-peralkaline" compositions.
The latter characteristic could arguably be imposed via
metasomatism, but the HFS element and REE patterns of the
latter are also consistent with transitional alkaline or
"A-type" character (e.g. Whalen et al., 1987), and are
independant of alteration (see Figure 7.9). Previous
conflicts over the affinity of Upper Aillik Group volcanism
are explicable if, as this study suggests, it shares the
characteristics of Makkovikian plutonism, i.e., it is
alkali-calcic to slightly peralkaline in composition,
rather than calc-alkaline in the original sense of the
word.

The Jagged Edge assemblage is, broadly speaking, closer in composition to the Bruce River Group than the Upper Aillik Group. It also lacks alkali disturbance seen in the Aillik Group and (as noted previously), is extremely fresh. Such characteristics suggest a possible equivalence to the Labradorian plutonic assemblage, but there is no geochronological proof of this as yet. The only unequivocal Labradorian suite in the general area is the Mount Benedict Intrusive Suite, but the incompatible element enrichment and lower SiO_2 content of these rocks does not correspond to the features of the Jagged Edge assemblage (Table 7.2). A further complication is provided by Nd isotope data, which give a distinctive mantle-like signature shared only by certain plutons of the Strawberry Intrusive Suite (Chapter 8). U-Pb zircon dating, preferably of a volcanic sample, is required to resolve these contradictions, and is planned. It is conceivable that these rocks are equivalents of the younger post-tectonic plutons such as the Strawberry Suite, but their geochemistry appears at variance with this interpretation.

It should be noted also that the data presented here do not cover all supracrustal rocks in the Benedict Mountains area, as Gower (1981) describes N or NE-trending foliations suggesting a Makkovikian age for localities on Double Island and Deus Cape.

CHAPTER EIGHT
ISOTOPE GEOCHEMISTRY

Chapter Abstract

Variable disturbance of the Rb-Sr isotopic system in the study area limits geochronological applications of the method, particularly in high-silica, Rb-enriched, granitoid rocks. Nevertheless, Makkovikian emplacement ages were obtained for the Big River Granite (1798 ± 28 Ma) and Freshsteak Granitoid (1798 ± 48 Ma). Both units have low initial Sr isotope ratios (< 0.703). An ambiguous age of 1714 ± 44 Ma was obtained from the Stag Bay Granitoid. Data from the Lanceground Intrusive Suite yield an apparent age of 1695-1670 Ma, but evidence for loss of radiogenic Sr suggests that this is an underestimate. A composite isochron from the Strawberry Intrusive Suite yields a similar age, and an unreasonably low initial Sr isotope ratio (< 0.698). This age is not in agreement with U-Pb ages of ca. 1760 Ma. High-silica granites of the Kennedy Mountain Intrusive Suite yield no useful Rb-Sr data, probably due to alkali disturbance and metasomatism.

Initial Sr isotope ratios from isochron studies of TLGB granitoid rocks in all areas generally lie within or slightly above the spectrum of mantle isotopic evolution. Few useful initial Sr isotope ratios can be obtained from single-sample Rb-Sr data, due to age uncertainties and generally high Rb-Sr ratios in granites. Also, the probable existence of depleted, granulite facies lower crust under the Archean Craton block limits the ability of Sr isotope data to distinguish mantle and crustal sources in this area. In contrast, Nd isotope geochemistry is much less sensitive to age and analytical uncertainty and, due to relatively constant Sm/Nd in crustal rocks, is a powerful indicator of source materials and their crustal residence periods.

Makkovikian plutonic and volcanic rocks display striking geographic variations in initial Nd isotopic composition. In the west of the area, Makkovikian units have ϵ_{Nd}CHUR of -3 to -14; these negative values indicate significant amounts of older (pre-1800 Ma) crust in their source materials. One unit (Brumwater Granite, ϵ_{Nd}CHUR = -14) was derived entirely by anatexis of Archean crust, but most have ϵ_{Nd}CHUR values above those predicted for Archean crust at ca. 1800 Ma. It is suggested that they represent variable mixtures of juvenile, mantle-derived magma and older sialic crust. Simplified mixing calculations indicate from 25% to 40% Archean component in these magmas, using reasonable assumptions about the juvenile end-member.

In the east of the area, units with equivalent bulk elemental geochemistry have ϵ_{Nd}CHUR from +1 to +6 ; these positive values

preclude significant contributions from Archean material, and the higher values are similar to those postulated for a depleted mantle reservoir at ca. 1800 Ma. Older crustal components, if present, must have had short crustal residence times.

The sharp boundary between these contrasting domains is interpreted as the eastern limit of Archean lower crust in the study area. Granites of the Strawberry Intrusive Suite show an east-west shift in ϵ_{Nd}CHUR from +6 to -6 across this line. The geochemical continuity of the suite suggests that the eastern plutons must include crustal contributions of similar magnitude to those indicated by negative ϵ_{Nd}CHUR in the west. It is therefore suggested that the eastern domain is floored by Proterozoic sialic crust generated during pre- Makkovikian or Makkovikian orogenic events. The Cape Harrison Metamorphic Suite may represent part of this basement, but it does not fulfill all isotopic requirements for the Strawberry Suite.

The Nd isotopic compositions of Makkovikian magmas were clearly influenced by the nature of local sialic crust. This suggests that crust-mantle interaction took place via direct melting, assimilation and homogenization of lower crust by mantle-derived, presumably mafic, juvenile magmas.

Labradorian plutonic and volcanic rocks show significantly less variation in ϵ_{Nd}CHUR, and compositions from gabbro to alaskitic granite have consistent ϵ_{Nd}CHUR values -1 to +1, i.e. they approximate bulk-earth compositions of 0. Geographic variations are subdued compared to those amongst Makkovikian units. There is evidence for crustal contamination in suites that had mafic parental magmas (Adlavik and Mount Benedict Suites), but the covariance of isotopic and major element compositions suggests that this was a high-level process that accompanied fractionation. Even mafic rocks of the Adlavik Suite have modest ϵ_{Nd}CHUR values of ca. +1, significantly lower than depleted mantle at 1650 Ma.

Derivation of these magmas from an undepleted mantle reservoir is unlikely in view of above evidence for depleted sources at 1800 Ma, and suites with mafic parental magmas cannot be derived by anatexis of older crustal material. It is concluded that Labradorian magmas are also mixtures of crustal and depleted mantle materials, but that the proportions of each are relatively constant and largely independent of the nature of the local lower crust. The proportion of older crust, assuming it approximates the Archean terrane, is probably no more than 10-15%. Similar "bulk-earth" characteristics in Proterozoic granitoids of other shield areas have been attributed to efficient subcrustal mixing and homogenization, possibly via the subduction of continent-derived sediment, as documented by studies of modern arc systems. This is a plausible and attractive explanation for some Labradorian magmas, but direct derivation by anatexis of Makkovikian crust remains possible for some granitoid units that lack associated mafic compositions.

Introduction

This chapter is concerned mostly with the use of Sr and (particularly) Nd isotopic systematics to constrain petrogenetic models. Rb-Sr geochronology is also employed in an attempt to determine the emplacement ages of several units. Although this method is inherently less precise than U-Pb zircon geochronology, it provides some constraints (probably minimum ages) that may be used to assign units to Labradorian or Makkovikian associations. Nd isotopic variations provide the best petrogenetic information, as Sr isotopic compositions are variably disturbed. Preliminary Nd isotope data from this project are reported by Kerr and Fryer (in press); this thesis provides data from a greater number of samples, and more detailed discussion of results.

Analytical Methods

All Sr and Nd isotope ratios were measured via thermal ionization mass-spectrometry at Memorial University, following separation of Sr and Nd by standard ion-exchange methods. $^{87}Rb/^{86}Sr$ ratios were determined by repeated high-precision Atomic Absorption (AA) Rb and Sr measurements at the Department of Mines Laboratory, and $^{147}Sm/^{144}Nd$ ratios were measured directly by high-precision Inductively-Coupled Plasma (ICP) mass spectrometry at Memorial University. Concentrations of Rb and Sr were measured by AA (Dept. of Mines), and Sm and Nd concentrations were measured by ICP-MS (MUN). Details of isotope analysis procedures are given in appendix A. Precision for concentration data is estimated at ± 5 %.

8.1 STRONTIUM ISOTOPE GEOCHEMISTRY

8.1.1 Rb-Sr Geochronology

Data and Methodology

Rb and Sr concentration and isotopic data employed in geochronology are listed in Table 8.1. All errors are within-run statistics quoted at the 95% confidence level (2 σ).

Isochron regressions were performed with a regression spreadsheet program written by H.Longerich of Memorial University, corresponding essentially to the method of York (1969). A decay constant for ^{87}Rb of 1.42 x 10 $^{-11}$ yrs $^{-1}$ (Steiger and Jager, 1977) was used in all isochron regressions.

The Mean Square of Weighted Deviates (MSWD) is used to assess the presence of scatter not accounted for by analytical error (Brooks et al., 1972); regressions with a MSWD value above 2.5 are termed errorchrons, and their uncertainty in age is amplified by the square root of the MSWD ($\sqrt{}$ MSWD). Analytical uncertainties used as input for regression are the 2 σ within-run values listed in Table 8.1; these represent a good approximation to 1 σ errors based on duplicate analyses (Appendix A), and are a conservative estimate of analytical uncertainty.

Constraints From Previous Rb-Sr Investigations

Previous Rb-Sr geochronological studies in the study area indicate that the Rb-Sr isotopic system is commonly disturbed and that results must be interpreted with caution.

Table 8.1. Rb-Sr concentration and isotopic data used for age
determinations. Some of the Sr data is also listed in Table 8.3.
Note that $^{87}Rb/^{86}Sr$ ratios are corrected for measured Sr
isotopic compositions. See Appendix A for analytical techniques.

Sample Number	Unit or Comment	CONCENTRATIONS (ppm)		ISOTOPE RATIOS					
		Rb	Sr	87Rb/86Sr	+/-	2 σ	87Sr/86Sr	+/-	2 σ
	BIG RIVER GRANITE								
0241137		193	79	7.209	+/-	71	0.887087	+/-	180
0241138		162	122	3.242	+/-	57	0.787668	+/-	110
0241158		150	117	3.070	+/-	31	0.781498	+/-	134
0241167		105	469	0.655	+/-	14	0.719634	+/-	52
0241538		132	126	3.081	+/-	74	0.779743	+/-	518
0241560		111	32	10.993	+/-	370	0.995702	+/-	1143
0241562		98	216	1.325	+/-	27	0.736004	+/-	104
	FRESHSTEAK GRANITOID								
0241286		97	408	0.694	+/-	14	0.721194	+/-	106
0241290		85	85	2.983	+/-	38	0.779526	+/-	120
0241305		81	413	0.569	+/-	7	0.718135	+/-	35
0241307		106	69	4.472	+/-	93	0.816171	+/-	60
0241308		130	65	5.968	+/-	127	0.860213	+/-	62
0241325		126	354	1.029	+/-	17	0.727454	+/-	62
0241342		64	443	0.416	+/-	7	0.713432	+/-	76
	STAG BAY GRANITOID								
0241164		134	116	3.347	+/-	60	0.783465	+/-	122
0241166		195	117	4.896	+/-	49	0.826132	+/-	72
0241253		65	801	0.236	+/-	5	0.709118	+/-	89
0249060		67	631	0.316	+/-	8	0.711426	+/-	69
AKZ-6		163	102	4.680	+/-	57	0.817134	+/-	60
	LANCEGROUND HILLS GRANITE								
0241152		130	69	5.529	+/-	87	0.834173	+/-	440
0241154		178	19	28.729	+/-	381	1.368654	+/-	628
0241332	Pistol Lk Granite	155	24	19.828	+/-	295	1.192142	+/-	1050
0248125		168	28	18.313	+/-	189	1.140939	+/-	668
0248126		169	35	14.613	+/-	143	1.052059	+/-	874
0249038		178	17	32.973	+/-	301	1.503070	+/-	1574
	STRAWBERRY INTRUSIVE SUITE								
0241391	Bayhead Granite	198	45	12.542	+/-	198	1.012539	+/-	296
AKZ-14	C.Strawberry Grnt	160	77	6.257	+/-	95	0.847986	+/-	82
AKZ-4	Dog Islands Grnt	153	76	5.984	+/-	111	0.842791	+/-	56
GSZ-1	Tukialik Granite	195	105	5.452	+/-	66	0.831219	+/-	230
GSZ-2	Tukialik Granite	164	19	27.009	+/-	283	1.349971	+/-	480
	KENNEDY MOUNTAIN INTRUSIVE SUITE								
0241020	Kennedy Mtn Grnt	135	19	22.424	+/-	230	1.333317	+/-	462
0241043	Narrows Granite	196	96	6.001	+/-	41	0.849300	+/-	1080
0241044	Narrows Granite	198	95	6.148	+/-	38	0.853896	+/-	240
0241068	Narrows Granite	170	77	6.523	+/-	73	0.862445	+/-	99
AKZ-13	Narrows Granite	103	78	3.864	+/-	63	0.801955	+/-	390
0241041	Long Is. Qz-mznznte	113	348	0.945	+/-	10	0.724362	+/-	62

NOTE: Errors in 87Rb/86 Sr are x 10^3, Errors in 87Sr/86Sr are x 10^6

In the west of the study area, several Rb-Sr ages
(White, 1976; Kontak, in Ryan, 1984; Brooks, 1982) are 50
to 150 Ma younger than subsequent U-Pb zircon age
determinations from the same units (Brooks, 1983; Schärer
et al., 1988). Most units in the west have undergone at least
minor Grenvillian tectonism, and isotopic disturbance may
be a function of these effects (MacKenzie and Wilton,
1988), or of post-crystallization magmatic-hydrothermal
activity (e.g. Walraven et al., 1986). Resetting of Rb-Sr
ages is not, however, restricted to areas near the
Grenville Front Zone, as the Round Pond Granite near
Makkovik yields a suspiciously young Rb-Sr age of less than
1500 Ma (D.Wilton and C.MacDougall, pers. comm., 1988).

In the eastern part of the TLGB, ages ranging from 1787
± 35 to 1677 ± 77 Ma from granitoid rocks in the Smokey
area (Owen et al., 1988) are broadly in agreement with the
ca. 1800 Ma U-Pb zircon ages subsequently obtained from
undeformed TLGB granitoid rocks in the study area (Krogh et
al., in prep.). Similarly, the 1625 ± 50 Ma Rb-Sr age from
the Mount Benedict Intrusive Suite (Brooks, 1982) agrees
generally with its U-Pb zircon age of 1650 ± 10 Ma (Krogh
et al., in prep.).

In summary, there are indications that Rb-Sr
geochronology can resolve Makkovikian and Labradorian
associations in the east of the study area at least.
Disturbance acts generally to lower apparent age, via
partial homogenization (Faure, 1978) or hydrothermal loss
of radiogenic Sr (e.g. Walraven et al., 1986). Rb-Sr ages
are therefore regarded conservatively as minimum estimates
of actual emplacement age.

Big River Granite

Seven samples were analyzed (Table 8.1; Figure 8.1a). These are regional geochemical samples collected from a relatively small (< 20 km^2) area in the north-central part of the body. All but one have the characteristic pseudorapakivi texture of the unit; the exception (0241560) is a coarse-grained, equigranular granite.

The data define an isochron (MSWD = 0.83), indicating an age of 1798 ± 28 Ma (2 σ), and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70173 ± 88 (2 σ). Sample 0241560 has a large error in $^{87}Rb/^{86}Sr$, but exclusion of this point does not affect the age significantly. The initial $^{87}Sr/^{86}Sr$ ratio is consistent with mantle compositions at ca. 1800 Ma (Faure and Powell, 1972), and the age is geologically reasonable[*]. It is therefore interpreted to date crystallization, and indicates that the Big River Granite is a post-tectonic Makkovikian Intrusion.

Freshsteak Granitoid

Seven samples were analyzed (Table 8.1; Figure 8.1c,d). These are regional samples clustered in the centre of the body; all are typical medium-grained melanocratic granitoid rocks, and show variable, but slight, recrystallization.

The data define an errorchron (MSWD = 4.67), indicating an age of 1776 ± 80 Ma (2 σ), and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70288 ± 94 (2 σ). If the age error is amplified

---

* NOTE : *Just prior to submission of this thesis, a U-Pb zircon age (concordant) of 1802 ± 2 Ma was obtained from this unit (Krogh et al., in prep.). This confirms (with greater precision) the Rb-Sr age obtained here.*
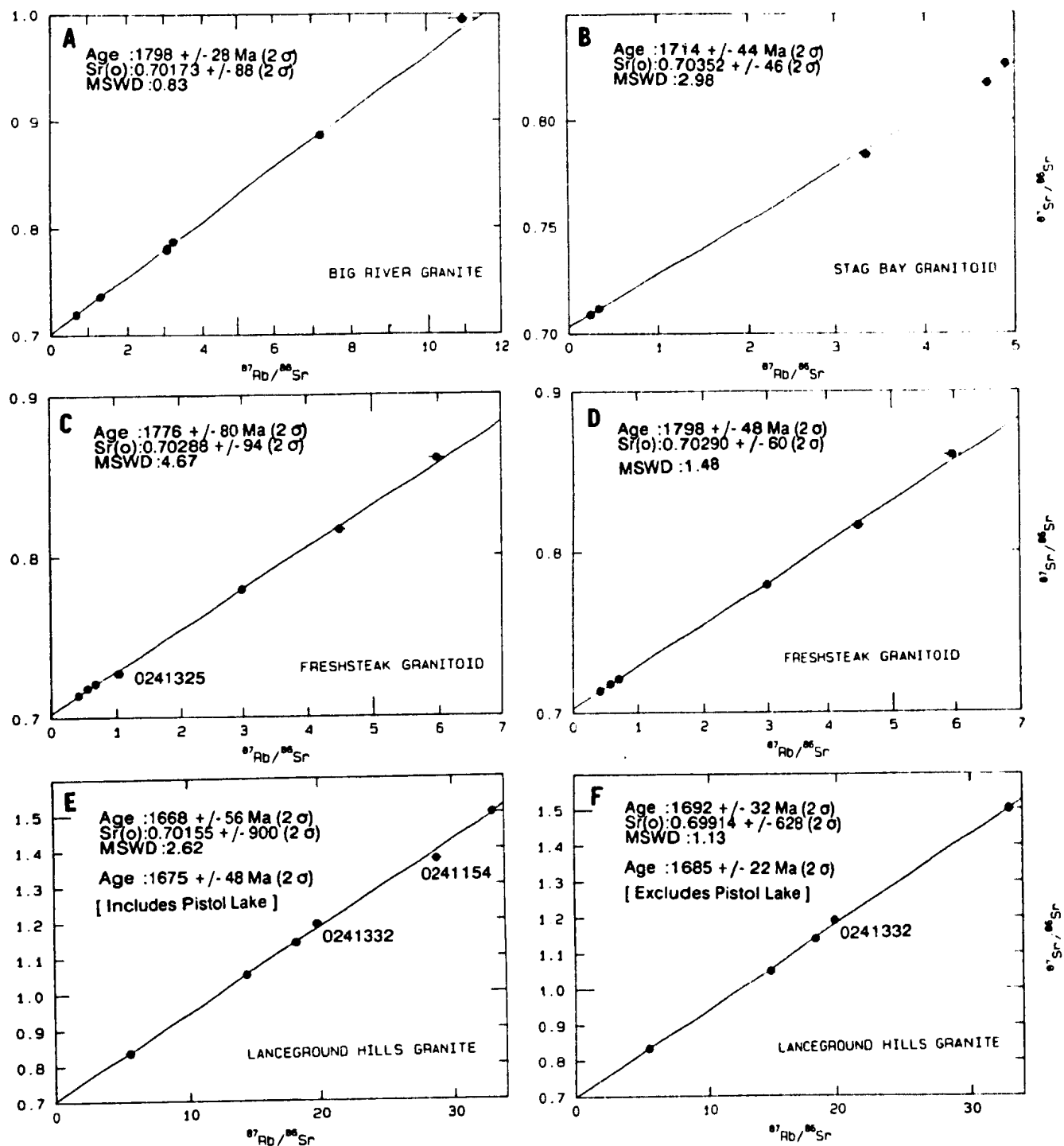
Figure 8.1. Rb-Sr isochron diagrams.(a) Big River Granite. (b) Stag Bay Granitoid. (c,d) Freshsteak Granitoid . (e,f) Lanceground Hills Granite (e,f). See text for discussion.

by $\sqrt{}$ MSWD, this becomes an inconclusive 1776 ± 173 Ma (2 σ). The high MSWD is a largely due to sample 0241325. If this is excluded, the data define an isochron (MSWD = 1.49) indicating an age of 1798 ± 48 Ma (2 σ) and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70290 ± 60 (2 σ). Sample 0241325 is saussuritized and epidotized relative to the other samples, and contains chlorite. Its position to the right of the isochron is consistent with a loss of radiogenic Sr, and the second result is thus preferred. Both age and initial ratio are geologically reasonable, and indicate that the Freshsteak Granitoid is a Makkovikian intrusion, of generally similar age to the Big River Granite.

Stag Bay Granitoid

Five samples from this unit were analyzed (Table 8.1; Figure 8.1b). These are regional geochemical samples distributed around Stag Bay, plus a geochronology sample (AKZ-6). The data define an errorchron (MSWD = 2.98), indicating an age of 1714 ± 44 Ma (2 σ), and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70352 ± 46 (2 σ). In view of the small number of samples, this is regarded here as an isochron. (c.f. Brooks et al., 1972; Fryer and Taylor, 1985).

The initial ratio is reasonable, but the age is between Makkovikian and Labradorian episodes, yet similar to Rb-Sr ages reported from granites in the Smokey area (Owen et al., 1988). As a minimum, it suggests a Makkovikian age * , but the error suggests a younger limit of 1670 Ma.

* NOTE : *Discordant U-Pb zircon data (Krogh et al., in prep., see note on p.243) indicate that this Rb-Sr age is too young, and the unit is 1790 - 1805 Ma old, i.e. of similar age to the Big River and Freshsteak units.*

Lanceground Intrusive Suite

Five samples from the Lanceground Hills Granite (within an 8 km^2 area), and one from the adjacent Pistol Lake Granite, were analyzed (Table 8.1; Figure 8.1e,f). All have high Rb/Sr ratios and are thus susceptible to loss of radiogenic Sr (c.f. Faure, 1978; Walraven et al., 1986).

Data for the Lanceground Hills Granite alone almost define an isochron (MSWD = 2.62) indicating an age of 1668 ± 46 Ma (2 σ), and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70155 ± 900 (2 σ). Sample 0241332 lies very close to this line, suggesting a similar age; regression of all data gives 1675 ± 48 Ma (2 σ). The large uncertainty in initial $^{87}Sr/^{86}Sr$ ratio reflects the very high $^{87}Rb/^{86}Sr$ (5 - 33) of all samples.

One sample (0241154) lies below the regression line. It is probable that this sample has lost radiogenic Sr, and the same may also be true of others. If it is excluded the fit is much better (MSWD = 1.13), and the age becomes 1692 ± 32 Ma (2 σ) or 1685 ± 22 Ma without the Pistol Lake Granite sample. Both produce unreasonably low (< 0.70) initial $^{87}Sr/^{86}Sr$ ratios, but with large uncertainties.

It is suggested that post-crystallization hydrothermal effects have reduced the apparent age with partial retention of isochron behaviour, similar to effects described by Walraven et al (1986). The age is thus interpreted as an underestimate, and the Lanceground Suite is regarded as a Makkovikian association, consistent with its distinctive trace element geochemistry (see 4.2).

Strawberry Intrusive Suite

Several samples analyzed from this suite as part of regional isotope geochemistry (see below) can be used to
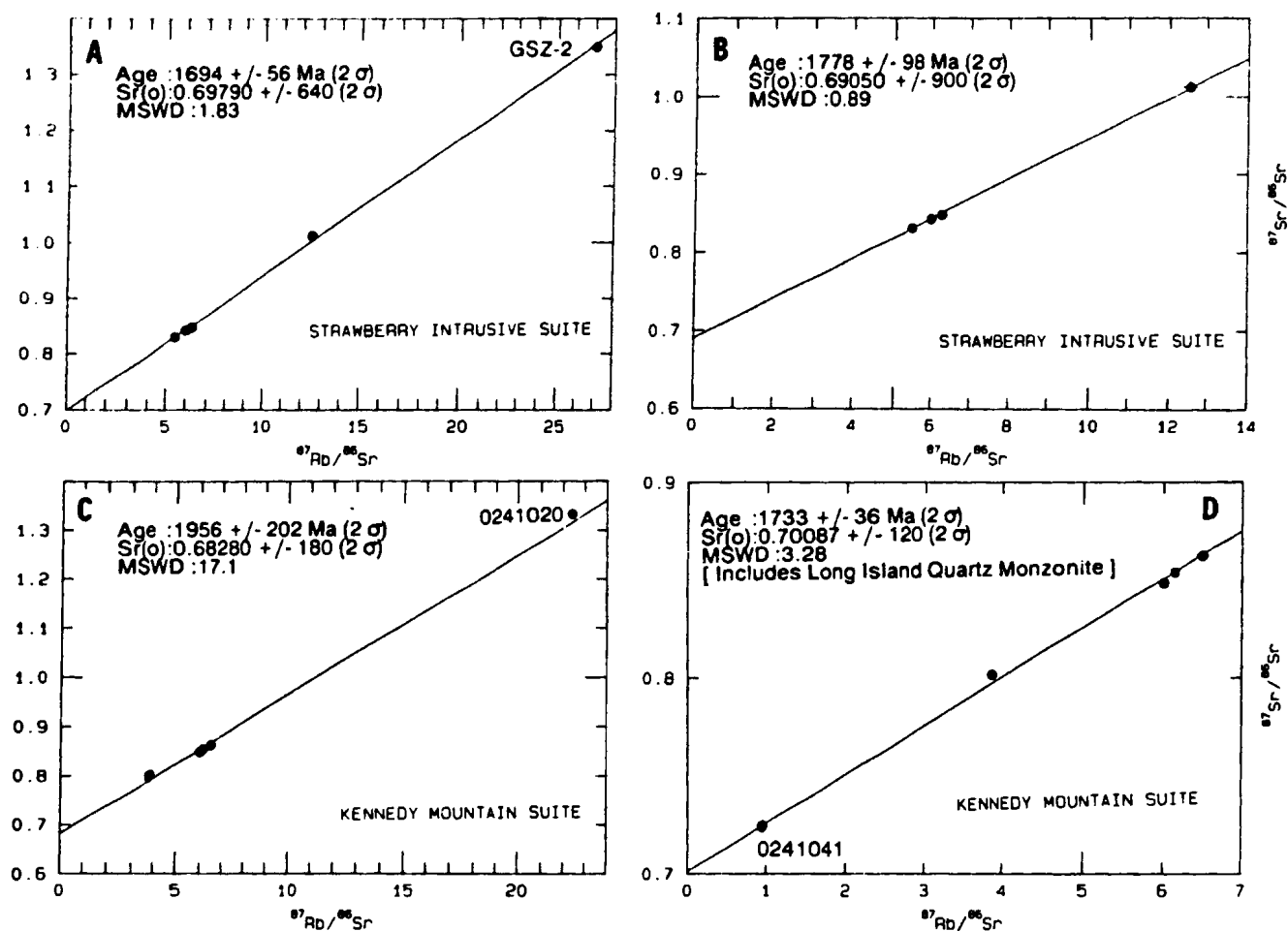
Figure 8.2. Composite Rb-Sr isochron diagrams. (a,b) Strawberry
Intrusive Suite. (c,d) Kennedy Mountain Intrusive Suite. See
text for discussion.

construct a composite isochron, but this is vulnerable to differences in initial $^{87}Sr/^{86}Sr$ between plutons. Five samples from the suite (Table 8.1; Figure 8.2a) define a surprisingly good line (MSWD = 1.83) yielding an age of 1694 ± 56 Ma (2 σ), and an initial $^{87}Sr/^{86}Sr$ ratio of 0.69790 ± 640 (2 σ). The large uncertainty in the initial ratio is due to the high $^{87}Rb/^{86}Sr$ of all samples.

The slope of this line is controlled by the most Rb-rich samples, in which isotopic disturbance is likely. If GSZ-2 is excluded (Figure 8.2b), the age becomes 1778 ± 98 Ma (2 σ), but the initial $^{87}Sr/^{86}Sr$ ratio is unreasonably low (0.69050 ± 900). Results are similar to those from the Lanceground Hills Granite (see above), but younger than the ca. 1760 Ma age indicated by U-Pb zircon data (Krogh et al., in prep.) for the Cape Strawberry Granite. The apparent Rb-Sr age is probably not significant in view of source differences between plutons indicated by Nd isotope data (see 8.2.2) and the high probability of disturbance in these rocks.

Kennedy Mountain Intrusive Suite

As discussed previously (3.2, 3.3), there is strong evidence for alkali-metasomatism in some members of this suite, and thus no reason to expect coherent isotopic behaviour. Four samples (mostly from the Narrows Granite; Table 8.1; Figure 8.2c) define an errorchron (MSWD = 17) indicating an age of 1956 ± 202 (2 σ), and an impossible initial $^{87}Sr/^{86}Sr$ ratio of 0.68280 ± 180. If amplified by $\sqrt{}$ MSWD, the age error is huge (> 800 Ma). The slope is controlled by sample 0241020, which has a very high $^{87}Rb/^{86}Sr$ ratio, and is probably disturbed.

As the unit intrudes the Upper Aillik Group, it cannot be older than 1860 Ma, and this "age" is meaningless. A more reasonable errorchron (MSWD = 3.28) age of 1733 ± 36 (2 σ) with an initial ratio of 0.70087 ± 120 (2 σ) is obtained if 0241020 is excluded (Figure 8.2d), and a sample from the possibly related Long Island Quartz Monzonite added. The rationale for doing this is, to say the least, tenuous, and no conclusions are drawn from these data.

8.1.2 Regional Variations In Sr Isotope Geochemistry

Sr_i Variation : Isochron Studies

Table 8.2 lists Sr_i values from the isochrons discussed above (preferred solutions), and published and unpublished data compiled from other Rb-Sr studies of TLGB granitoid rocks (sources listed in table). It should be noted that some of these ages are known, or suspected, to be disturbed, and their Sr_i values are similarly suspect. In most isochrons, however, Sr_i is fixed by the sample with lowest Rb/Sr and is hence less subject to disturbance than is the age.

Sr_i values from isochrons in all parts of the TLGB fall dominantly within the field of $^{87}Sr/^{86}Sr$ ratios for the mantle in the interval from 2000 to 1400 Ma (Figure 8.3a; Faure and Powell, 1972). Isochrons with Sr_i below mantle evolution are mostly known to be disturbed. Several Sr_i values lie above the mantle spectrum; these include the Makkovikian Island Harbour Bay Intrusive Suite (data of Grant et al., 1983), and possibly disturbed isochrons from the Labradorian Witchdoctor, Burnt Lake and Otter Lake - Walker Lake units. There is no apparent systematic variation in Sr_i values between different portions of the TLGB.

Table 8.2. Initial Sr isotopic compositions calculated from Rb-Sr
isochrons throughout the Trans-Labrador Granitoid Belt (this and
previous studies).

Unit or Suite	Age	+/- 2 σ	Sr(o)	+/- 2 σ	Source
WESTERN TLGB SEGMENT (West of L.Michikamau)					
Monzonite, Churchill Falls	1720	+/- 55	0.70253	+/- 28	Brooks, 1982
Granite, Michikamau Lake	1715	+/- 100	0.70260	+/- 22	Brooks, 1982
North Pole Brook Int. Suite	1669	+/- 36	0.70250	+/- 40	Fryer, 1984
North Pole Brook Int. Suite	1637	+/- 12	0.70290	+/- 20	Fryer, 1984
North Pole Brook Int. Suite	1709	+/- 188	0.70240	+/- 100	Fryer, 1984
North Pole Brook Int. Suite *	1513	+/- 100	0.70450	+/- 120	Fryer, 1984
Blueberry Lake Group *	1540	+/- 40	0.70370	+/- 80	Brooks, 1979
CENTRAL TLGB SEGMENT (L.Michikamau to Michelin area)					
Island Harbour Bay Int. Suite	1794	+/- 71	0.70440	+/- 30	Grant et al., 1983
Island Harbour Bay Int. Suite	1805	+/- 42	0.70200	+/- 150	Grant et al., 1983
Island Harbour Bay Int. Suite	1843	+/- 90	0.70440	+/- 30	Grant et al., 1983
Foliated Granitoid, Anna Lake*	1795	+/- 50	0.70500	+/- 80	Brooks, 1979
Witchdoctor Granite	1595	+/- 34	0.70380	+/- 30	Brooks, 1979
Burnt Lake Granite	1548	+/- 90	0.70673	+/- 356	MacKenzie and Wilton, 1988
Otter Lk - Walker Lk Granite	1548	+/- 73	0.70718	+/- 85	Kontak, in Ryan, 1984
Otter Lk - Walker Lk Granite *	1498	+/- 46	0.70517	+/- 98	Kontak, in Ryan, 1984
Bruce River Group Volcanics *	1506	+/- 40	0.70109	+/- 56	Kontak, in Ryan, 1984
Bruce River Group Volcanics *	1530	+/- 35	0.70717	+/- 56	Kontak, in Ryan, 1984
Bruce River Group Volcanics *	1526	+/- 42	0.70380	+/- 150	Wanless and Loveridge, 1972
Upper Aillik Group *	1786	+/- 38	0.69589	+/- 124	Kontak, in Ryan, 1984
EASTERN TLGB SEGMENT (Michelin area to Smokey Islands)					
Cape Harrison Met. Suite	1740	+/- 85	0.70340	+/- 60	Brooks, 1982
Mount Benedict Intr. Suite	1625	+/- 50	0.70160	+/- 240	Brooks, 1982
"Late" Syenite, Benedict Mtns	1725	+/- 135	0.70240	+/- 410	Brooks, 1982
Granodiorite, Smokey Area	1787	+/- 35	0.70233	+/- 20	Owen et al., 1988
Monzodiorite, Smokey Area	1697	+/- 41	0.70400	+/- 50	Owen et al., 1988
Granite, Smokey Area	1725	+/- 31	0.70320	+/- 60	Owen et al., 1988
Big River Granite	1798	+/- 28	0.70173	+/- 88	This study
Freshsteak Granitoid	1798	+/- 48	0.70290	+/- 60	This study
Stag Bay Granitoid	1714	+/- 44	0.70352	+/- 46	This study
Lanceground Hills Granite *	1692	+/- 32	0.69914	+/- 628	This study
Strawberry Int. Suite (comp) *	1694	+/- 56	0.69790	+/- 640	This study
Round Pond Granite Stock *	1483	+/- 40	0.70584	+/- 213	Wilton and MacDougall (unpublished)

NOTE : All errors in initial 87Sr/86Sr ratios are x 10^5
* This age has been shown to be, or is suspected to be, disturbed.

Table 8.3. Initial Sr isotopic compositions calculated from single sample measurements conducted via this study, using ages based on U-Pb and Rb-Sr determinations. Note that samples with high Rb/Sr ratios generally give unreasonable values.

Sample Number	Unit and Comments	Assumed Age	87Rb/86Sr Mean +/- 2 σ	87Sr/86Sr Mean +/- 2 σ	87Sr/86Sr(I) Mean +/- 2 σ
Syn-tectonic Makkovikian Intrusive / Extrusive Rocks					
AKZ-15*	Upper Aillik Gr., Ranger Bight	1850	16.701 +/- 534	1.092711 +/- 136	0.64815 +/- 1434
W84138*	Upper Aillik Gr., Michelin	1850	9.656 +/- 149	0.914201 +/- 67	0.65718 +/- 403
AKZ-2	Manak Island Granitoid	1800	0.313 +/- 5	0.710627 +/- 281	0.70253 +/- 42
0241041*	Long Island Quartz Monzonite	1800	0.945 +/- 10	0.724362 +/- 62	0.69990 +/- 31
	[Kennedy Mountain Intrusive Suite]				
0241020	Kennedy Mountain Granite	1800	22.424 +/- 230	1.333317 +/- 462	0.75276 +/- 642
AKZ-13	Narrows Granite	1800	3.864 +/- 63	0.801955 +/- 390	0.70191 +/- 202
AKZ-11	Melody Granite	1800	7.379 +/- 130	0.887209 +/- 186	0.69616 +/- 356
Post-tectonic Makkovikian Intrusive Rocks					
	[Numok Intrusive Suite]				
AKZ-3	Monzonite to Quartz Monzonite	1800	3.322 +/- 63	0.780105 +/- 130	0.69410 +/- 175
AKZ-5*	Syenite to Quartz Syenite	1800	1.368 +/- 33	0.734527 +/- 64	0.69911 +/- 92
	[Strawberry Intrusive Suite]				
0241391	Bayhead Granite	1760	12.542 +/- 198	1.012539 +/- 296	0.69514 +/- 542
AKZ-14	Cape Strawberry Granite	1760	6.257 +/- 95	0.847986 +/- 82	0.68965 +/- 253
AKZ-4	Dog Islands Granite	1760	5.984 +/- 111	0.842791 +/- 56	0.69137 +/- 292
GSZ-1	Tukialik Granite	1760	5.452 +/- 66	0.831219 +/- 230	0.69324 +/- 194
GSZ-2	Tukialik Granite	1760	27.009 +/- 283	1.349971 +/- 480	0.66645 +/- 780
	[Lanceground Intrusive Suite]				
0241154	Lanceground Hills Granite	1800	28.729 +/- 381	1.368654 +/- 628	0.62488 +/- 1048
0241332	Pistol Lake Granite	1800	19.828 +/- 295	1.192142 +/- 1050	0.67881 +/- 868
0241538	Big River Granite	1800	3.081 +/- 74	0.779743 +/- 518	0.69998 +/- 243
0241286	Freshsteak Granitoid	1800	0.694 +/- 14	0.721194 +/- 106	0.70323 +/- 47
Labradorian Intrusive and Extrusive Rocks					
0241173	Adlavik Intr. Suite Gabbro	1650	0.032 +/- 5	0.703137 +/- 133	0.70239 +/- 24
0249030*	Adlavik Intr. Suite Diorite	1650	0.314 +/- 9	0.711421 +/- 108	0.70399 +/- 32
GSZ-4	M.Benedict Intr. Suite Syenite	1650	11.535 +/- 198	0.945953 +/- 496	0.67250 +/- 520
AKZ-12	Monkey Hill Granite	1650	3.489 +/- 50	0.782133 +/- 440	0.69943 +/- 162
AKZ-7	Witchdoctor Granite	1630	22.602 +/- 439	1.224032 +/- 498	0.69479 +/- 1077
AKZ-8	Otter Lk - Walker Lk Granitoid	1650	1.358 +/- 20	0.736971 +/- 106	0.70477 +/- 58
AKZ-9	Otter Lk - Walker Lk Granitoid	1650	1.203 +/- 21	0.730720 +/- 106	0.70219 +/- 61
BR84187*	Bruce River Group Volcanic	1650	18.580 +/- 354	1.142885 +/- 149	0.70242 +/- 855
Other					
AKZ-6	Stag Bay Granitoid	1725	4.680 +/- 57	0.817134 +/- 60	0.70107 +/- 146

* Age constrained by Precise U-Pb determination
NOTE : Errors in 87Rb/86Sr are x 10^3, errors in initial 87Sr/86Sr are x 10^5

At face value, these Sr_i values indicate derivation largely from the mantle, with variable admixtures of older continental crust enriched in radiogenic Sr. However, studies of high-grade gneisses indicate that granulite-facies rocks commonly have very low Rb/Sr ratios that differ only minimally from postulated upper mantle compositions (e.g. Faure, 1978). Lower crustal rocks of this type are known to exist in the Archean Nain Province (Collerson and Bridgwater, 1979), and cannot be precluded as sources on the basis of Sr isotope data alone. They may, however, be identified via Nd geochemistry (see 8.2).

Sr_i Variation : Single Sample Data

If the age of a rock is known, Sr_i may be calculated from the systematics of a single sample. This method has been used widely in Phanerozoic and recent rocks (e.g. Thirlwall, 1982; Pankhurst et al.,1988; Hildreth and Moorbath, 1988), and has even been applied to Archean amphibolites (Wooden and Mueller, 1988). Table 8.3 lists Sr isotope data and calculated Sr_i for a subset of the 48 samples analyzed for Nd compositions, using ages based on U-Pb zircon or whole-rock Rb-Sr dates. Information on these samples is listed subsequently (Table 8.5). Calculated Sr_i values vary wildly, and many fall well below mantle evolution (Figure 8.3b; Faure and Powell, 1972). In general, only samples with low $^{87}Rb/^{86}Sr$ (< 3.0) have calculated Sr_i values that are geologically reasonable (Table 8.3).

Problems In Calculating Sr_i

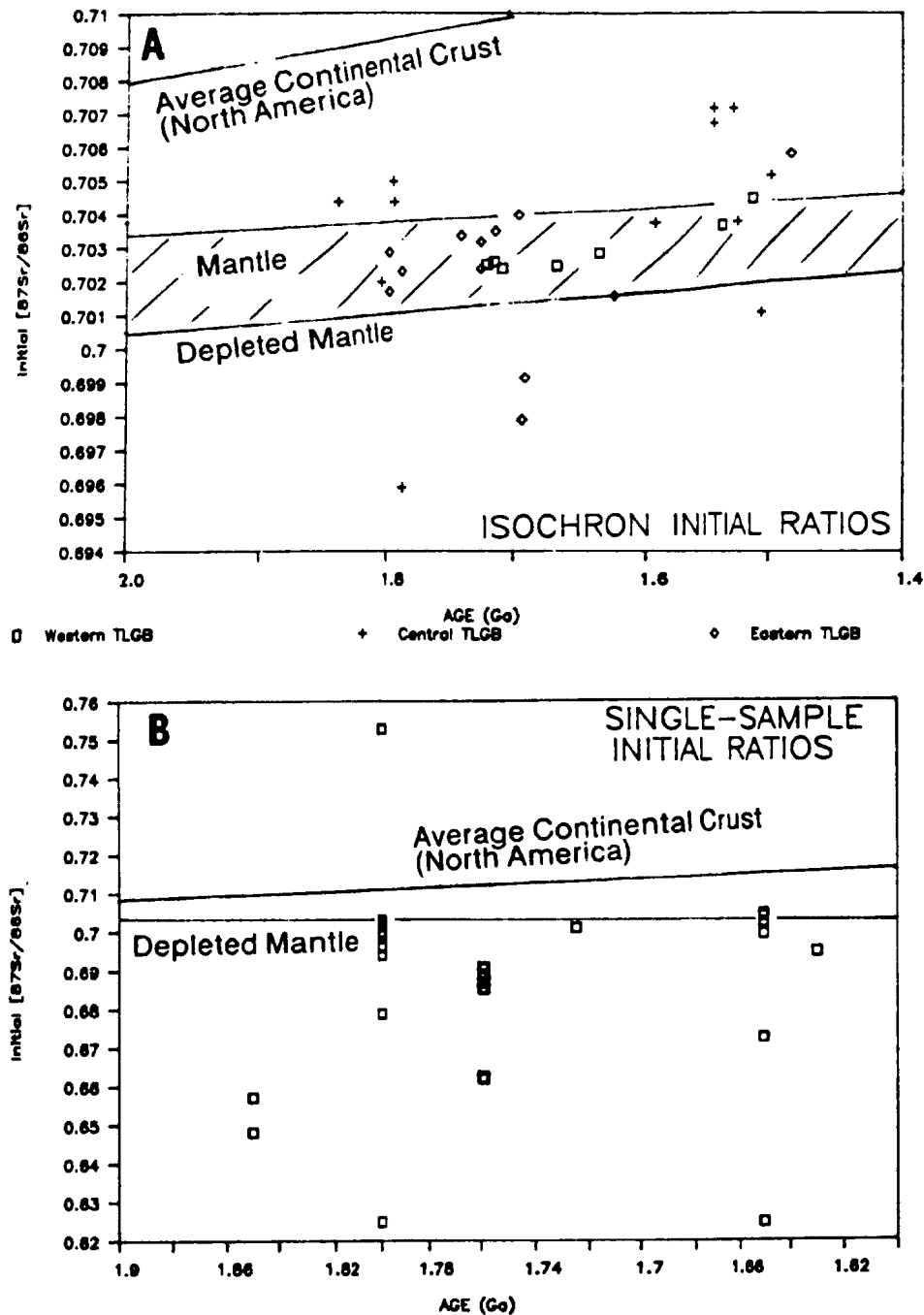TLGB granitoid rocks present significant problems for single-sample Sr_i studies. Firstly, their age allows

Figure 8.3. Initial Sr isotopic compositions with reference to postulated mantle evolution. (a) initial ratios calculated from isochrons. (b) initial ratios calculated by extrapolation from single-sample data. Sources for isochron data are listed in Table 8.2. Mantle growth band after Faure and Powell (1972).

ample time for Sr isotope evolution, increasing the
magnitude of corrections required for isotopic growth.
Secondly, large uncertainties in $^{87}Rb/^{86}Sr$ resulting
from generally high Rb/Sr ratios propagate during
extrapolation to 0 to obtain Sr_i, and generate very large
errors (e.g. Table 8.3). Thirdly, even slight loss of
radiogenic Sr from high Rb/Sr samples displaces their
calculated Sr_i to unreasonably low values. A consequence
of these problems is that calculated Sr_i is extremely
sensitive to small variations in assumed age. Note that the
2 σ uncertainties listed in Table 8.3 do not include
possible age uncertainty (see 8.2.2 for details of error
calculation methods).

These problems are illustrated by three samples (Table
8.4), dated by precise U-Pb zircon methods (Schärer et al.,
1988; Krogh et al., in prep.). Sample 0249030, which has a
low $^{87}Rb/^{86}Sr$ ratio, produces a reasonable Sr_i value
that changes only minimally if its assumed age is altered
by up to 100 Ma. In contrast, BR-84-187 ($^{87}Rb/^{86}Sr$ =
18.6), which provides a reasonable result using its U-Pb
zircon age of 1650 Ma, has a range of calculated Sr_i (for
a 100 Ma range) that covers the full range from basaltic
achondrites to evolved continental crust ! Sample
W-84-138, dated precisely at ca. 1850 Ma, shows similarly
extreme behaviour, and impossibly low Sr_i at all assumed
ages, presumably resulting from loss of radiogenic Sr. In
contrast, all three show only small changes in calculated
initial Nd isotopic composition (expressed as $\epsilon_{Nd}CHUR$;
see 8.2.2) as a result of age uncertainty.

No further attempt is made here to use calculated
whole-rock Sr_i values. The only solution is to separate
and analyze minerals with low Rb/Sr ratios, such as
plagioclase or (ideally) apatite or sphene, in which
measured $^{87}Sr/^{86}Sr$ deviates only minimally from Sr_i.

Table 8.4. An illustration of the great sensitivity of rocks with high Rb/Sr ratios to age uncertainties in the calculation of initial Sr isotopic compositions from a single sample. Note that Initial Nd isotopic compositions, expressed as ϵ_{Nd}CHUR, are much less sensitive to variations in assumed age.

Assumed Age	Calculated [87Sr/86Sr]o	+/- Estimated 2 σ Error	Calculated ϵ(Nd)CHUR	+/- Estimated 2 σ Error

SAMPLE 0249030 (Adlavik Intrusive Suite Diorite)
87Rb/86Sr = 0.31, 147Sm/144Nd = 0.1099

1700	0.70376		0.30	
1675	0.70387		0.02	
★ 1650	0.70398	+/- 32	- 0.26	+/- 0.82
1625	0.70410		- 0.54	
1600	0.70421		- 0.83	

SAMPLE W-84-138 (Upper Aillik Group Rhyolite)
87Rb/86Sr = 9.66, 147Sm/144Nd = 0.0978

1900	0.65014		- 4.83	
1875	0.65336		- 5.15	
★ 1850	0.65718	+/- 403	- 5.47	+/- 1.0
1825	0.66070		- 5.79	
1800	0.66421		- 6.11	

SAMPLE BR-84-187 (Bruce River Group Felsic Volcanic)
87Rb/86Sr = 18.6, 147Sm/144Nd = 0.1014

1700	0.68890		0.09	
1675	0.69566		- 0.22	
★ 1650	0.70241	+/- 854	- 0.53	+/- 0.68
1625	0.70917		- 0.84	
1600	0.71591		- 1.14	

★ Indicates age given by precise U-Pb zircon determination

8.2 NEODYMIUM ISOTOPE GEOCHEMISTRY

Neodymium as a Petrogenetic Tool

Neodymium has inherent advantages over strontium in isotopic studies of Precambrian granitoid rocks.

Sm/Nd ratios vary minimally in crustal rocks (their mean $^{147}Sm/^{144}Nd$ is estimated at ca. 0.115 ± 0.01; Goldstein et al., 1984), and this ratio is largely independent of magmatic differentiation. Age corrections to obtain initial Nd isotopic compositions are small compared to those required for Sr (due to the long half-life of ^{147}Sm), and are almost constant for all rock types (e.g. Table 8.4). The uncertainty in correcting single-sample data is thus much smaller than for Sr.

The coherent behaviour of Sm and Nd reflects the supposed inability of crustal processes to strongly fractionate two closely similar rare-earth elements. There are, however, significant differences in Sm/Nd between the crust and values inferred for the mantle on the basis of meteorite studies (e.g. DePaolo and Wasserburg, 1976). The initial Nd isotopic composition of crustal rocks thus constrains the time elapsed since their precursor(s) separated from the mantle, regardless of the number of times this material was "reprocessed" in the crust. In this regard, Sm and Nd differ radically from Rb and Sr, which

Figure 8.4. Locations of samples analyzed in neodymium isotope geochemistry study. Some of these (see Table 8.3) were also analyzed for Sr. See Table 8.5 for sample and unit details. Note that sample BR-84-187 (from the Bruce River Group) lies to the west of the study area. It is from the outcrop located by Scharer et al.(1988).

are strongly fractionated by magmatic processes in the crust, and commonly undergo multi-stage evolution in crustal reservoirs (e.g. Faure and Powell, 1972).

Finally, Nd and Sm reside primarily in accessory and mafic phases (as opposed to feldspars), and are generally less subject to disturbance by hydrothermal activity or alteration, although the REE may be mobile under certain conditions (e.g. Taylor and Fryer, 1982; Windrim et al., 1984).

Such flawless behaviour is, of course, subject to exceptions! McCulloch and Black (1984), and Windrim et al.(1984), have discussed the effects of granulite facies metamorphism and hydrothermal processes on Sm and Nd behaviour, and the unusual isotopic characteristics of the Pitre Lake Granite determined in this study (see 8.3.1) imply local strong fractionation of Sm from Nd during anatexis. The geochronological applications of Sm and Nd indicate that there must be slight fractionation of Sm and Nd during igneous processes (O'Nions et al., 1979), but it is minimal compared to that observed for Rb and Sr.

Overview of Neodymium Isotope Geochemistry Database

Nd isotopic data are reported here for 48 samples; about half of these were also analyzed for Sr isotopic composition (see 8.1.2; Sr results listed in Table 8.3).

The samples are representative examples of major geological units, and (wherever possible) are from localities for which U-Pb zircon dates are available or planned. All samples are listed and described in Table 8.5, and located in Figure 8.4. In addition to the plutonic and volcanic rocks, two orthogneisses from the Cape Harrison Metamorphic Suite (Gower, 1981) were analyzed to

Table 8.5. Listing of samples analyzed for Nd isotopic compositions,
with descriptive comments and age information. Sample locations
are shown in Figure 8.4. Note that some of these were also
analyzed for Sr (see table 8.3 for results)

SAMPLE	Unit	Age	Description and Comments
SYN-TECTONIC MAKKOVIKIAN PLUTONIC ROCKS			
0241041	Long Island Quartz Monzonite	1802 +13/-10 Ma [U-Pb Zr]	Hb-Bi Quartz Monzonite, close to location dated by Gandhi et al.(1988).
	KENNEDY MOUNTAIN INTRUSIVE SUITE		
0241020	Kennedy Mountain Granite		Fluorite-bearing biotite granite.
AKZ-13	Narrows Granite	Not Yet	Biotite-Hornblende Monzogranite.
0251058	Cross Lake Granite	Dated	Biotite granite with fluorite, allanite.
0241060	Cross Lake Granite		Porphyritic Bi-Hb leucogranite.
	ISLAND HARBOUR BAY INTRUSIVE SUITE (Samples provided by Bruce Ryan)		
0140067	Homogeneous granite unit	1805 +/- 5 Ma [U-Pb Zr]	Porphyritic biotite granite, part of unit dated by Loveridge et al.(1987).
0140037	Tonalite-granodiorite unit		Melanocratic Bi-Hb granodiorite.
	OTHER SYN-TECTONIC MAKKOVIKIAN GRANITOIDS		
AKZ-11	Melody Granite	Not	Porphyritic biotite granite, hematized.
0249213	Brumwater Granite	Yet	biotite monzogranite, faintly layered.
0249195	Pitre Lake Granite	Dated	biotite-muscovite granite.
AKZ-2	Manak Island Granitoid		leucocratic, slightly porphyritic, granodiorite.
0249015	Deus Cape Granitoid	1837 +6/-4 Ma [U-Pb Zr]	Porphyritic, leucocratic granite. Dated by Krogh et al., in prep.)
POST-TECTONIC MAKKOVIKIAN PLUTONIC ROCKS			
	NUMOK INTRUSIVE SUITE		
AKZ-5	Syenite (Northern Zone)	1801 +/- 2 Ma [U-Pb Zr]	Coarse grained Cpx-fayalite syenite dated by Krogh et al.(in prep.)
AKZ-3	Quartz Monzonite (Northern Zone) (Adjacent to agmatitic border)	1801 +/- 2 Ma [U-Pb Zr]	Coarse grained Hb-Bi (Px) quartz monzonite ca. 2 km from dated locality.
0241338	Quartz Syenite (Southern Zone)	Not Dated	Slightly deformed porphyritic quartz syenite.
	STRAWBERRY INTRUSIVE SUITE		
AKZ-14	Cape Strawberry Granite	1800-1760 Ma [U-Pb Zr]	Coarse grained, porphyritic biotite granite, with accessory fluorite. Dated by Krogh et al.(in prep.)
0241391	Bayhead Granite		
0241181	October Harbour Granite	Not	Coarse grained, porphyritic, biotite
AKZ-4	Dog Islands Granite	Yet	granites similar to AKZ-14.
GSZ-1	Tukialik Granite	Dated	
GSZ-2	Tukialik Granite		
	LANCEGROUND INTRUSIVE SUITE		
0241154	Lanceground Hills Granite	1692 +/- 32 Ma [Rb-Sr WR]	Coarse-grained Bi-Hb alkali-fsp granite; age is probably disturbed.
0241332	Pistol Lake Granite	Not Yet	Porphyritic alkali-fsp quartz syenite.
0248101	Tarun Granite	Dated	Coarse grained granite, slightly deformed.
	OTHER POST-TECTONIC MAKKOVIKIAN GRANITOIDS		
0241538	Big River Granite	1798 +/- 28 Ma [Rb-Sr WR]	Coarse-grained Hb-Bi granite with pseudorapakivi texture.
0241286	Freshsteak Granitoid	1798 +/- 48 Ma [Rb-Sr WR]	Medium-grained melanocratic Hb-Bi quartz monzonite.
0241356	Noarse Lake Granitoid	Not Dated	Similar to above.

Table 8.5

SAMPLE	Unit	Age	Description and Comments
	LABRADORIAN PLUTONIC ROCKS		
	ADLAVIK INTRUSIVE SUITE		
0241173	Gabbro Unit (Main Body)	Not	Olivine gabbronorite.
0249062	Gabbro Unit (Pamiulik Point)	Yet	Melanocratic olivine gabbronorite.
0241441	Gabbro Unit (East MicMac Lake)	Dated	Hornblende gabbro, minor interstitial K-tsp
0249030	Diorite Unit (Main Body)	1649 +/- 1 Ma [U-Pb Zr]	Potassic monzodiorite to syenodiorite dated by Krogh et al (in prep.)
	MOUNT BENEDICT INTRUSIVE SUITE		
0242136	Diorite Unit		Plag-porphyritic (cumulate?) Cpx-diorite.
0242144	Monzonite to Syenite Unit	1650 +/- 10 Ma [U-Pb Zr]	Syenite with relict Plag-porphyritic texture. Dated by Krogh et al.(in prep.)
GSZ-4	Quartz Syenite	1625 +/- 50 Ma [Rb-Sr WR]	Similar to above, but richer in quartz. Dated by Brooks (1982), probably disturbed.
	MONKEY HILL INTRUSIVE SUITE		
AKZ-12	Monkey Hill Granite	1640 +/- 10 Ma [U-Pb Zr]	Fine-grained biotite monzogranites.
0248191	Little Monkey Hill Granite		Monkey Hill Granite dated by Krogh et al.(in prep.)
	OTHER LABRADORIAN GRANITOIDS		
AKZ-7	Witchdoctor Granite	1628 +/- 9 [U-Pb Zr]	Recrystallized Bi (Ms) leucogranite with accessory garnet. Site dated by Brooks (1983).
0249074	Burnt Lake Granite		Fine grained, leucocratic Bi (Ms) granite.
AKZ-8	Otter Lake - Walker Lake Gran	1548 +/- 73 Ma [Rb-Sr WR]	Quartz Monzonite to Monzogranite with phenocrysts of both feldspars. Same area dated by Kontak (in Ryan, 1984).
	UNCLASSIFIED PLUTONIC ROCKS		
AKZ-6	Stag Bay Graniotid	1714 +/- 44 Ma [Rb-Sr WR]	K-feldspar porphyritic Hb-Bi granodiorite to monzogranite.
0242030	Thunder Mountain Syenite	Not Dated	Coarse grained Cpx-Hb quartz syenite.
	VOLCANIC ROCKS		
	UPPER AILLIK GROUP		
AKZ-15	Early Upper Aillik Group ?	1861 +9/-3 Ma [U-Pb Zr]	Thin rhyolite flow or sill in metased- -iments. Sample dated by Scharer et al.(1988).
W84138	Late Upper Aillik Group ? (provided by R.J.Wardle)	1856 +/- 2 Ma [U-Pb Zr]	Weakly deformed rhyolitic ash-flow tuff. Sample dated by Scharer et al.(1988).
0248237	Hypabyssal Intrusive Rocks	1807 +/- 2 Ma [U-Pb Zr]	Quartz-feldspar porphyry. Same locality as sample dated by Scharer et al.(1988).
0249324	Jagged Edge Assemblage	Not Dated	Fresh feldspar-porphyry.
	BRUCE RIVER GROUP		
BR84187	Sylvia Lake Formation (Provided by B.Ryan)	1649 +/- 1 Ma [U-Pb Zr]	Weakly deformed rhyolitic ash-flow tuff. Same locality as sample dated by Scharer et al. (1988).
	CAPE HARRISON METAMORPHIC SUITE		
AKZ-20	Tonalitic gneiss unit	Not Yet Dated	Grey, foliated, locally banded tonalitic to granodioritic gneiss.
AKZ-21	Foliated Granodiorite		Homogeneous, leucocratic, foliated granodiorite or monzogranite.

represent possible "basement" in the east of the area. No
samples from the Archean basement rocks in the west of the
area were analyzed; however, data for these are provided by
Brooks (1983). Note that the Freshsteak and Noarse Lake
granitoids are here grouped as Makkovikian intrusions,
based on Rb-Sr data (8.1.1).

8.2.1 Sm-Nd "Geochronology"

Sm and Nd are of limited value as geochronometers in
post-Archean rocks (e.g. O'Nions et al., 1979; Cox et al.,
1979). However, isochron diagrams may define quasi-linear
trends that may be significant in terms of other processes
such as mixing and variation in initial $^{143}Nd/^{144}Nd$
ratios amongst units. "Ages" were obtained by least-squares
regression as outlined previously (8.1.1), but no attempt
is made to assess them statistically; they are quoted
mostly as an indication of the slope of correlations
relative to those expected for isochron behaviour. Sm and
Nd concentration and isotopic data are listed subsequently
(Tables 8.6; 8.7). A ^{147}Sm decay constant of 6.54 x
10^{-12} yr^{-1} (Steiger and Jager, 1977) was used in
calculation of age, and subsequent calculation of ϵ_{Nd}
(see 8.2.2 for details of the latter).

Syn-Tectonic Makkovikian Plutonic Rocks

Units in the west of the study area mostly define a
1553 ± 330 Ma (2 σ) pseudoisochron (Figure 8.5a), except
for AKZ-11 and 0249213, which are below this line. Units
from the east (Manak Island and Deus Cape; AKZ-2, 0249015)
lie well above this line and, with AKZ-13 and two samples
from the Cape Harrison Metamorphic Suite, define a 2046 ±

694 Ma (2 σ) pseudoisochron. Sample 0249195 (Pitre Lake Granite) has an anomalous $^{147}Sm/^{144}Nd$ ratio (ca. 0.23) and lies well to the right of the diagram; it is discussed separately (8.3.1).

Post-Tectonic Makkovikian Plutonic Rocks

No obvious pattern exists amongst these samples (Figure 8.5b); possible "ages" range from 2741 Ma to 3364 Ma, depending upon which samples are included in the regression. Assuming that groupings based on petrology and elemental geochemistry (Chapter 4) are valid, this points to differences in their initial Nd isotopic composition. This is shown well by six samples from the Strawberry Intrusive Suite (Figure 8.5c), which are highly variable; their apparent age of 4516 ± 680 Ma (1 σ), is meaningless, and AKZ-14 and AKZ-4 both lie well away from this "line". Note that 5 of these samples (including the two most deviant) define a reasonably well-fitted composite 1695 Ma Rb-Sr isochron (8.1.1). In view of their strong petrological and geochemical affinity (Chapter 4), this variation indicates significant differences in initial Nd isotopic composition, that are apparently not present for Sr. Note that the highest $^{143}Nd/^{144}Nd$ values are from plutons in the east (Tukialik and Dog Islands Granites; GSZ-1, GSZ-2, AKZ-4). Plutons in the west lie close to the lower pseudoisochron described above from syn-tectonic Makkovikian units and, if regressed with 3 samples from the Kennedy Mountain Suite and one from Long Island, yield a reasonable 1902 ± 142 Ma (2 σ) pseudoisochron (Figure 8.5c).
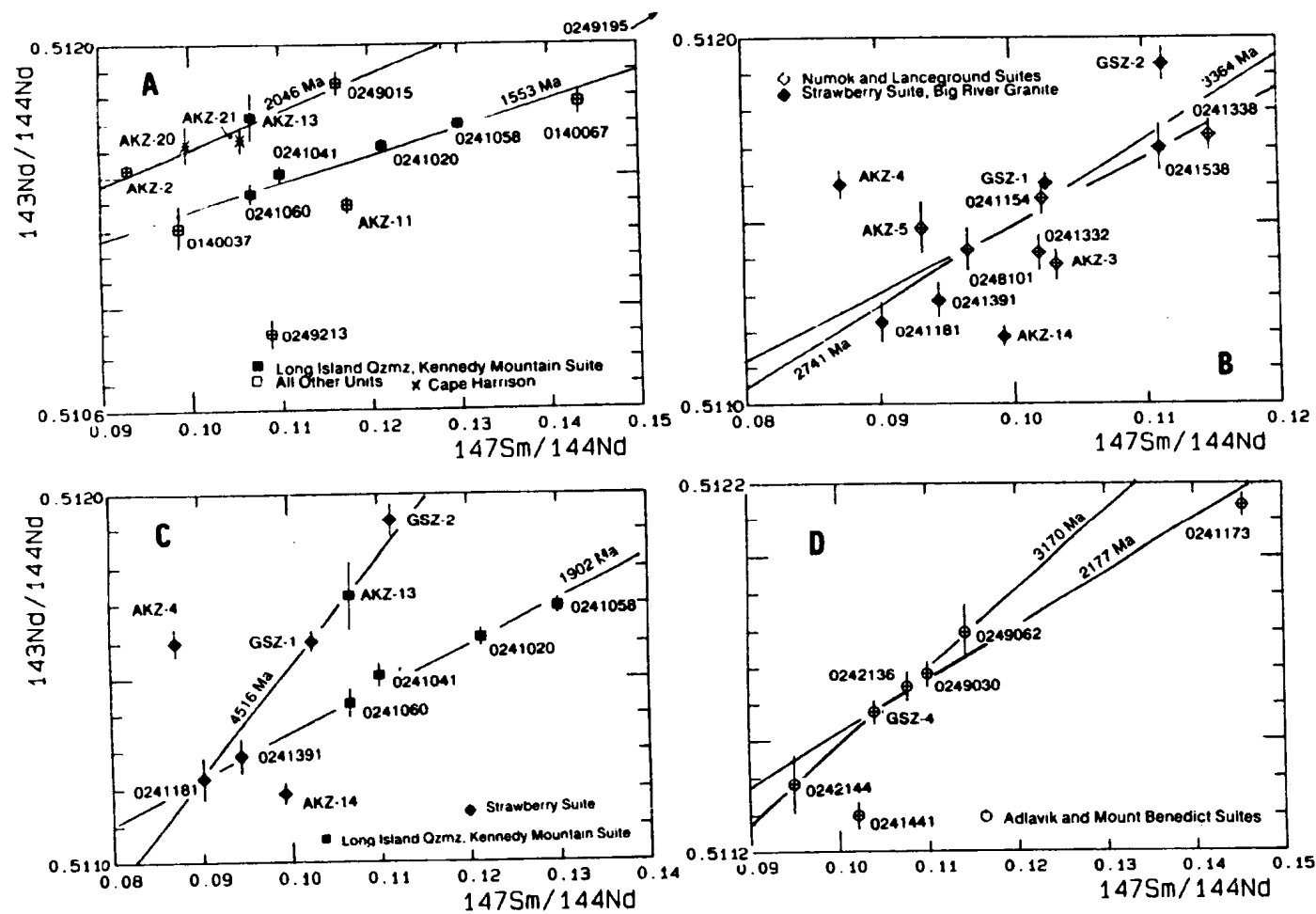
Figure 8.5. Sm-Nd isochron diagrams. (a) Syn-tectonic Makkovikian units. (b) Post-tectonic Makkovikian units. (c) Detail of Strawberry and Kennedy Mountain Suites. (d) Adlavik and Mount Benedict Suites. See text for discussion.

Labradorian Plutonic Rocks

The ca. 1650 Ma old Adlavik and Mount Benedict
Intrusive Suites (excluding 0241441; a gabbro from East
MicMac Lake) define a 2177 ± 410 Ma (2 σ) pseudoisochron
(Figure 8.5d). The slope is strongly influenced by sample
0241173; if this is excluded, the remaining samples define
a 3170 ± 217 Ma (2 σ) pseudoisochron. A similar age is
defined by three samples from the Mount Benedict Suite
alone. This "age" is obviously untenable. This
pseudoisochron could be interpreted as an argument against
a genetic relationship but the presence of a linear array
would be a remarkable coincidence under such conditions.
Also, there is independent geochemical evidence for a
genetic link (Chapter 5). An alternative explanation is
that the more differentiated rocks are variably
contaminated by material with low $^{147}Sm/^{144}Nd$ and
$^{143}Nd/^{144}Nd$, i.e. this is a steepened isochron. Binary
mixing of this type would produce a linear array. A similar
proposal was advanced by Ashwal et al.(1986) to explain
anomalously old (3300 Ma) Sm-Nd isochron ages from the ca.
1300 Ma old Harp dykes of central Labrador.

Labradorian granitoid plutonic rocks (not figured)
define no obvious trends in isochron diagrams, and, in
general, show much less variation in present-day
$^{143}Nd/^{144}Nd$ than their Makkovikian counterparts.
Similar comments apply to unclassified units from Stag Bay
and Thunder Mountain.

8.2.2 Regional Variations In Nd Isotope Geochemistry

Sm and Nd concentration and isotopic data are listed in
Tables 8.6 and 8.7, with the calculated parameters
$\epsilon_{Nd}CHUR$, $\epsilon_{Nd}DM$ and T_{DM}. (DePaolo and Wasserburg,

1976; DePaolo, 1979). All errors are within-run statistics quoted at the 2 σ level; errors for $^{147}Sm/^{144}Nd$ are calculated as $\pm$ 0.5%, based on duplicate analyses (see Appendix A).

Data Notation and Representation

Epsilon (ϵ_{Nd}) Notation : The initial $^{143}Nd/^{144}Nd$ ratio of a sample at time T is readily calculated from the radioactive decay equation, assuming that $^{147}Sm/^{144}Nd$ and T are known. It is conventional to represent initial Nd compositions as ϵ_{Nd} *units* (DePaolo, 1979). These indicate deviations (in parts per 10^4) from the calculated $^{143}Nd/^{144}Nd$ of a reference material that evolved with a known $^{147}Sm/^{144}Nd$ ratio. Unless an age is specifically stated, ϵ_{Nd}, as used below, refers to Nd isotopic compositions at the time of formation, i.e. time of crystallization.

ϵ_{Nd} is commonly expressed relative to a chondritic uniform reservoir (CHUR), for which accepted present-day values (employed here) are $^{143}Nd/^{144}Nd$ = 0.512638 and $^{147}Sm/^{144}Nd$ = 0.196593 (Jacobsen and Wasserburg, 1980; normalized to a $^{146}Nd/^{144}Nd$ ratio of 0.7219). The parameter ϵ_{Nd} at time T is given by the expression:

$$\epsilon_{Nd}CHUR = 10^4 \times \left[\frac{^{143}Nd/^{144}Nd_{(sample)} \text{ at } T}{^{143}Nd/^{144}Nd_{CHUR} \text{ at } T} - 1 \right]$$

Negative $\epsilon_{Nd}CHUR$ values indicate initial $^{143}Nd/^{144}Nd$ ratios below chondritic evolution (typical of crustal material, with a lower Sm/Nd ratio than the

mantle) and positive values indicate derivation from
material that has a $\underline{higher}$ Sm/Nd than CHUR. Positive
ϵ_{Nd}CHUR values are common in modern and ancient mafic
extrusive rocks (e.g. Nelson and DePaolo, 1984; White and
Patchett, 1984). They indicate that substantial portions of
the earth's mantle were depleted in Nd relative to Sm at an
early stage; this is inferred to result from the extraction
of the continental crust.

As post-Archean crust formation probably tapped this
depleted mantle reservoir, the notation ϵ_{Nd}DM is also
widely employed, indicating initial $^{143}Nd/^{144}Nd$
relative to postulated depleted mantle evolution. However,
there is no firm concensus regarding the isotopic evolution
of the mantle, and ϵ_{Nd}CHUR values are preferable for
comparison of data from different sources. ϵ_{Nd}DM values
quoted below are with reference to evolution from ϵ_{Nd}CHUR
of ca +2 at ca. 2800 Ma to ca + 5 at ca. 1800 Ma ago (c.f.
Patchett and Bridgwater, 1984; Chauvel et al., 1987). This
is consistent with observed ϵ_{Nd}CHUR values for ca. 1700
Ma old mafic volcanics of up to + 6 (Nelson and DePaolo,
1984). For the sake of simplicity, mantle evolution over
this time interval is assumed here to be linear.

Model Ages and Crustal Residence Ages : A Nd Model
age is the time at which the $^{143}Nd/^{144}Nd$ ratio of a
sample and a reference material (model) have the same
value. In the ϵ_{Nd} notation used here, T_{CHUR} is the time
at which ϵ_{Nd}CHUR = 0, and T_{DM} the time at which ϵ_{Nd}DM
= 0. In each case there is a unique solution, which can be
calculated by iteration or equations presented by DePaolo
(1979,1981b). The key assumption is that, if a sample is
the end product of a multi-stage crustal process, its Sm/Nd
ratio has not changed significantly since its initial
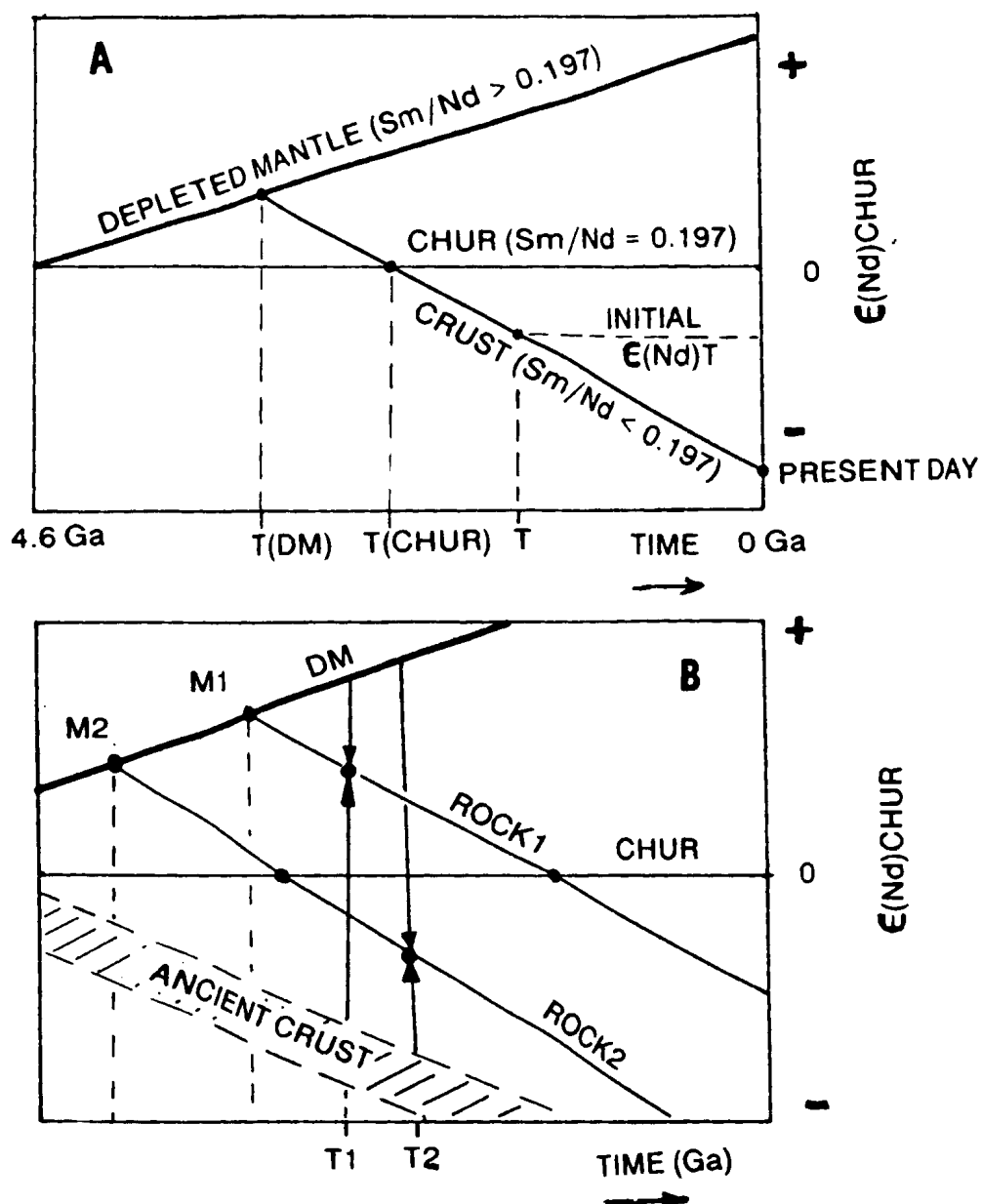
Figure 8.6. Schematic illustrations of the principles of Nd isotope geochemistry. (a) Contrasting variation of crustal material and depleted mantle relative to CHUR, and geometric representation of model ages T_{DM} and T_{CHUR}. (b) Complications due to mixed sources; model ages M1 and M2 for two rocks result from different mixtures of mantle- and crustal-derived magmas, and have no true geochronological meaning. Adapted partly from Arndt and Goldstein (1987).

derivation from the mantle. Extrapolation of its Nd isotopic growth line back to CHUR or DM evolution lines thus provides the earliest time at which it or its precursor(s) could have been generated from such a source (Figure 8.6a).

It is important to note that the above is true only if the sample was derived from a single source material with a simple history. If a rock is derived from two or more sources themselves derived from the mantle at different times (e.g. a juvenile magma assimilating much older crust; Figure 8.6b), any Nd model age is a function of the relative proportions and Nd contents of these end members and has no direct geochronological significance (e.g. Patchett and Bridgwater, 1984; Arndt and Goldstein, 1987). Nevertheless, there may be situations in which model ages reflect the actual time at which the precursor separated from the mantle, particularly when model ages correspond with orogenic events documented via geochronology.

Estimation of Uncertainty : Analytical uncertainty in ϵ_{Nd} and T_{DM} was calculated using a "worst-case" scenario where $^{143}Nd/^{144}Nd$ and $^{147}Sm/^{144}Nd$ both deviate by 2 σ in opposite directions. As it is highly unlikely that perfect anticorrelation of errors would occur, an arbitrary value corresponding to 66% of this worst-case error is used below to indicate 2 σ uncertainty. In most cases (Tables 8.6; 8.7) this is ± 0.7 ϵ_{Nd} units or less. Errors due to age uncertainties are more difficult to assess; however, variations of ± 50 Ma in assumed age (e.g. Table 8.4) cause only small changes in ϵ_{Nd}, that are within analytical errors, and have a negligable impact on model age calculations.

Age Assumptions : Ages assumed in calculations are
listed in Tables 8.6 and 8.7; in most cases these are based
on U-Pb or Rb-Sr geochronology, rounded to the nearest 10
Ma. For some units of uncertain age, values were calculated
for both 1800 and 1650 Ma, or for an intermediate value of
1725 Ma. ϵ_{Nd} Values for Archean gneisses (Brooks, 1983)
are calculated for 2600 Ma (Sm/Nd isochron age, probably
metamorphic; Brooks, 1983), 1800 Ma and 1650 Ma; the latter
values indicate their characteristics during Makkovikian
and Labradorian magmatism respectively. An age of 1850 Ma
has been assumed for the Cape Harrison Metamorphic Suite,
by reasoning that it predates the Deus Cape Granitoid (ca.
1840 Ma; Krogh et al., in prep.), and its ϵ_{Nd} at ca. 1650
Ma is also listed.

Syn-Tectonic Makkovikian Plutonic Rocks

ϵ_{Nd}CHUR values for these units range from -13.8 to
+3.6 (Table 8.6). Units in the west of the area mostly have
negative ϵ_{Nd}CHUR (generally < -2.0), whereas those in the
east have ϵ_{Nd}CHUR of ca. +3.0. The Narrows Granite of the
Kennedy Mountain Suite (sample AKZ-13; ca. + 3.0) is an
exception to this pattern. Positive values in the east are
similar to those of the Cape Harrison Metamorphic Suite at
an assumed 1850 Ma age. This confirms pseudoisochron
behaviour noted above (8.2.1).

In the east, T_{DM} model ages are ca. 2000 - 1950 Ma
for the Manak Island and Deus Cape Granitoids, and also for
the Cape Harrison Suite. As the latter is undated, its
model age may correspond to its time of formation. These
values indicate that the precursor(s) to units in the east
had a short crustal residence period, probably less than
200 Ma (subject to qualifications previously outlined with

Table 8.6

	GENERAL INFORMATION		CONCENTRATIONS		ISOTOPIC RATIOS		INITIAL Nd CHARACTERISTICS		
Sample Number	Unit or Comments	Age (Ma)	Sm (ppm)	Nd (ppm)	147Sm/144Nd Mean +/- 2σ	143Nd/144Nd Mean +/- 2σ	ε(Nd)CHUR Mean +/- 2σ	ε(Nd)DM Mean	T(DM) Mean +/- 2σ
SYN-TECTONIC MAKKOVIKIAN PLUTONIC ROCKS									
0241041	Long, Island Qzmz	1800	6.9	38.1	0.1100 +/- 55	0.511511 +/- 33	-2.9 +/- 0.5	-7.0	2290 +/- 47
KENNEDY MOUNTAIN INTRUSIVE SUITE									
0241020	Kennedy Mtn Granite	1800	12.2	59.4	0.1214 +/- 61	0.511615 +/- 25	-2.6 +/- 0.4	-1.6	2390 +/- 44
AKZ-13	Narrows Granite	1800	10.6	59.0	0.1068 +/- 53	0.511725 +/- 90	-3.0 +/- 1.3	-2.0	1940 +/- 110
0241058	Cross Lake Granite	1800	13.9	63.7	0.1299 +/- 65	0.511695 +/- 20	-3.0 +/- 0.4	8.0	2485 +/- 42
0241060	Cross Lake Granite	1800	13.6	75.5	0.1067 +/- 53	0.511433 +/- 39	-2.8 +/- 0.6	-1.7	2325 +/- 51
ISLAND HARBOUR BAY INTRUSIVE SUITE									
0141001	Granite Unit	1800	4.6	18.8	0.1434 +/- 72	0.511776 +/- 48	-4.5 +/- 0.7	-9.5	2760 +/- 108
0140037	Tonalite-Granodior.	1800	5.5	32.6	0.0987 +/- 49	0.511310 +/- 81	-3.3 +/- 1.1	-8.3	2325 +/- 91
OTHER UNITS									
AK-11	Melody Granite	1800	7.8	42.4	0.1175 +/- 59	0.511388 +/- 29	-6.1 +/- 0.5	-11.1	2632 +/- 45
0240215	Brumwater Granite	1800	2.6	13.9	0.1088 +/- 54	0.510894 +/- 55	-13.8 +/- 0.8	-18.8	3100 +/- 72
0240145	Pitts Lake Granite	1800	7.5	19.6	0.2262 +/- 113	0.512892 +/- 32	-1.9 +/- 0.6	-6.9	n/a
AKZ-2	Manak Is Granitoid	1800	7.4	15.5	0.0930 +/- 47	0.511529 +/- 26	2.3 +/- 0.4	-2.7	1960 +/- 31
0240015	Bras Cape Granitoid	1840	8.6	43.0	0.1165 +/- 58	0.511851 +/- 47	3.6 +/- 0.7	-1.3	1940 +/- 69
POST TECTONIC MAKKOVIKIAN PLUTONIC ROCKS									
NUMOK INTRUSIVE SUITE									
AKZ-3	Monzonite (N.Zone)	1800	16.7	94.4	0.1030 +/- 51	0.511126 +/- 26	-4.0 +/- 0.4	-9.0	2390 +/- 35
AKZ-5	Syenite (N zone)	1800	7.9	50.8	0.0933 +/- 47	0.511485 +/- 69	1.4 +/- 1.0	-3.6	2020 +/- 74
0241300	Qz Syenite (S Zone)	1800	12.0	69.4	0.1149 +/- 57	0.511734 +/- 41	1.3 +/- 0.6	-3.7	2080 +/- 60
STRAWBERRY INTRUSIVE SUITE									
0241391	Raxhead Granite	1760	9.0	57.7	0.0944 +/- 47	0.511288 +/- 47	-3.3 +/- 0.7	-8.4	2275 +/- 53
AKZ-16	Cape Strawberry Grnt	1760	9.9	63.1	0.0993 +/- 50	0.511188 +/- 29	-6.3 +/- 0.5	-11.4	2490 +/- 37
0241181	October Hr. Granite	1760	10.6	71.3	0.0902 +/- 45	0.511228 +/- 56	-3.5 +/- 0.8	-8.6	2275 +/- 59
AKZ-4	Dog Islands Granite	1760	10.5	72.0	0.0872 +/- 44	0.511606 +/- 50	4.6 +/- 0.7	-0.5	1790 +/- 51
GSZ-1	Tuktalik Granite	1760	6.7	39.3	0.1026 +/- 51	0.511605 +/- 28	1.1 +/- 0.4	-4.0	2025 +/- 37
GSZ-2	Tuktalik Granite	1760	13.9	73.0	0.1114 +/- 56	0.511927 +/- 46	5.4 +/- 0.7	0.3	1740 +/- 63
LANGELROND INTRUSIVE SUITE									
0241170	Langroun Granite	1800	26.8	156.2	0.1023 +/- 51	0.511363 +/- 43	0.8 +/- 0.6	-4.2	2075 +/- 55
0241172	Pistol Lk Granite	1800	22.9	133.9	0.1020 +/- 51	0.511418 +/- 50	-1.9 +/- 0.7	-6.9	2250 +/- 60
0240121	Laton Granite	1800	11.9	73.6	0.0966 +/- 48	0.511426 +/- 60	-0.6 +/- 0.9	-5.5	2150 +/- 67
OTHER UNITS									
0241308	Bip River Granite	1800	9.8	54.8	0.1111 +/- 56	0.511701 +/- 61	1.5 +/- 0.9	-3.5	2050 +/- 81
0241380	Freshstock Granitoid	1800	8.1	42.9	0.1099 +/- 55	0.511575 +/- 81	-0.7 +/- 1.1	-5.7	2200 +/- 105
0241340	Moarse Lk Granitoid	1800	8.1	41.7	0.1127 +/- 56	0.511576 +/- 40	-1.3 +/- 0.6	-6.3	2250 +/- 57

GENERAL INFORMATION			CONCENTRATIONS		ISOTOPIC RATIOS		INITIAL Nd CHARACTERISTICS		
Sample Number	Unit or Comments	Age (Ma)	Sm (ppm)	Nd (ppm)	147Sm/144Nd Mean +/- 2σ	143Nd/144Nd Mean +/- 2σ	ϵ(Nd)CHUR Mean +/- 2σ	ϵ(Nd)DM Mean	T(DM) Mean +/- 2σ
MAKKOVIKIAN VOLCANIC ROCKS									
284138	U.Aillik, Michelin	1850	8.4	51.3	0.0978 +/- 49	0.511156 +/- 50	-5.5 +/- 0.7	-10.3	2500 +/- 58
AKZ-15	U.Aillik, Ranger B.	1850	13.2	56.4	0.1395 +/- 70	0.511956 +/- 39	0.2 +/- 0.6	-4.6	2290 +/- 85
0248257	White Bear Mtn. Qzfp	1810	12.6	68.6	0.1100 +/- 55	0.511657 +/- 36	1.0 +/- 0.6	-4.0	2090 +/- 50
0249324	Jagged Edge Area	1810	13.7	59.7	0.1371 +/- 69	0.512157 +/- 28	4.5 +/- 0.5	-0.5	1860 +/- 62
"BASEMENT" ROCKS	(Archean Gneiss Data from Brooks, 1983)								
ARCHEAN BASEMENT									
M1-AV	Layered Gneiss (n=3)	2600	3.9	26.0	0.0995 +/- 50	0.510697 +/- 35	-5.4 +/- 0.6	-8.0	3110 +/- 46
M2-AV	Layered Gneiss (n=2)	2600	4.1	23.6	0.1105 +/- 55	0.510910 +/- 21	-5.0 +/- 0.4	-7.5	3130 +/- 36
M1-AV	Layered Gneiss (n=3)	1800	Calculations For The Same Samples At T = 1800 Ma				-15.5 +/- 0.5	-20.5	3110 +/- 43
M2-AV	Layered Gneiss (n=2)	1800					-13.9 +/- 0.4	-18.9	3130 +/- 33
CAPE HARRISON METAMORPHIC SUITE									
AKZ-20	Tonalitic Gneiss	1850	5.8	35.4	0.0996 +/- 50	0.511623 +/- 70	3.2 +/- 1.0	-1.6	1950 +/- 80
AKZ-21	Granodiorite Gneiss	1850	3.2	18.1	0.1057 +/- 53	0.511639 +/- 48	2.1 +/- 0.7	-2.7	2035 +/- 61

NOTES: Initial Neodymium Compositions are calculated assuming CHUR values of
147Sm/144Nd = 0.196593 and 143Nd/144Nd = 0.512638 (Present Day)
DM values are with respect to ϵ(Nd)CHUR(2800) = +2 and ϵ(Nd)CHUR(1800) = +5 (Linear Evolution)
Errors in 147Sm/144Nd are x 10^4, Errors in 143Nd/144Nd are x 10^6

Table 8.6. Sm and Nd concentration and isotopic data for Makkovikian plutonic and volcanic rocks, and basement rocks in the east and west at ca. 1800 Ma.

respect to model ages). It also indicates unequivocally that the Cape Harrison Metamorphic Suite is of Proterozoic, and not Archean, age.

T_{DM} model ages in the west vary from 3100 Ma to 1940 Ma, but are mostly older than 2300 Ma. The ca. 3100 Ma model age for the Brumwater Granite is close to the probable formation age of the Archean gneisses (Loveridge et al., 1987), and, with its very low ϵ_{Nd}CHUR value, indicates that this unit was derived from Archean crustal material. This result is consistent with the gradational relationship with surrounding migmatites described by Marten (1977).

Most other units in the west have ϵ_{Nd}CHUR values higher than the Archean gneisses, and model ages that are younger than 3000 Ma. They cannot therefore be derived entirely from Archean crust formed prior to 3000 Ma, although they may incorporate some of this material.

Similar values of -2.0 to -3.0 for the Long Island unit and two granites of the Kennedy Mountain Intrusive Suite support the suggestion that they are related (Chapter 3), and had similar source(s); however, the value for the Narrows Granite (+3.0) is inconsistent. Note, however, that this is imprecise compared to the other samples, and should carry less weight .

The Pitre Lake Granite, which appears to be a product of anatexis, has surprisingly high ϵ_{Nd}CHUR (-1.9), considering its sedimentary protolith, and a very high $^{147}Sm/^{144}Nd$ ratio (see 8.3.1 for further discussion).

Post-Tectonic Makkovikian Plutonic Rocks

ϵ_{Nd}CHUR values for these rocks vary widely (Table 8.6).

In the Numok Intrusive Suite, syenites from northern and southern zones both have ϵ_{Nd}CHUR of ca. +1.4. However, quartz monzonite from near to the agmatitic western border of the suite in the northern zone has an anomalous low value of -4.0, and a high Nd content (94 ppm).

Granites from the Strawberry Intrusive Suite display remarkable variation. Three plutons in the west (Bayhead, Cape Strawberry and October Harbour Granites) have ϵ_{Nd}CHUR of -6.0 to -3.0, whereas those in the east (Dog Islands and Tukialik Granites) have ϵ_{Nd}CHUR of up to +5.0. There are obviously profound differences in the sources of these rocks from east to west. The Lanceground Hills and Tarun Granites have identical ϵ_{Nd}CHUR (within error) of ca. 0; the Pistol Lake Granite is slightly, but significantly, lower (-1.9).

To summarize, post-tectonic Makkovikian units show negative ϵ_{Nd}CHUR in the west, and positive ϵ_{Nd}CHUR in the east -- a pattern very similar to that of their syn-tectonic counterparts (see above).

Most units have negative ϵ_{Nd}DM, indicating some component of older crustal material, except for the eastern plutons of the Strawberry Intrusive Suite, which are very close to depleted mantle evolution (i.e. ϵ_{Nd}DM = 0). If these granites have a crustal component, it has a crustal residence time below isotopic resolution. Several units in the east have consistent T_{DM} model ages of ca. 2000 Ma, similar to those noted above for the syn-tectonic units.

Makkovikian Volcanic Rocks

The Upper Aillik Group at Ranger Bight has an approximate bulk-earth value (ϵ_{Nd}CHUR = 0) for 1850 Ma whereas the Michelin Ridge locality has a low value (-5.5).

The White Bear Mountain porphyry has a moderate (+1.0) value. This is just within error of the adjacent Tarun Granite, which may be a plutonic equivalent of the porphyry. If the Jagged Edge assemblage porphyry is Makkovikian, it would have ϵ_{Nd}CHUR of +4.5. Amongst plutonic rocks, only the eastern plutons of the Strawberry Intrusive Suite show such characteristics.

On the basis of 4 samples, it is an act of faith to discuss geographic variation; however, the eastward change from -5.5 to +4.5 is consistent with patterns in Makkovikian plutonic rocks described above.

Labradorian Plutonic and Volcanic Rocks

In general, Labradorian rocks show less variation in ϵ_{Nd}CHUR than their Makkovikian counterparts (Table 8.7; also Figure 8.7). Most samples are clustered around bulk-earth ϵ_{Nd}CHUR values of ca. 0.

In the Adlavik Intrusive Suite, units from the main body and Pamiulik Point areas have similar ϵ_{Nd}CHUR of ca. +1.0 to -0.5. However, a gabbro from the westernmost intrusion at East MicMac Lake has significantly lower ϵ_{Nd}CHUR of -6.1, indicating a crustal input. Three samples from the Mount Benedict Intrusive Suite have variable, slightly negative ϵ_{Nd}CHUR. The lowest value (-2.9, but with a large error) is shown by quartz syenite (0242144) from the most evolved unit. As a group, the Adlavik and Mount Benedict Suites (excluding 0241441) show a smooth progression from values of ca. +1.0 in mafic rocks to ca. -2.0 in syenite and granite, consistent with their Sm-Nd pseudoisochron behaviour (8.2.1).

Sample Number	Unit or Comments	Age (Ma)	Sm (ppm)	Nd (ppm)	147Sm/144Nd Mean +/- 2σ	143Nd/144Nd Mean +/- 2σ	ε(Nd)CHUR Mean +/- 2σ	ε(Nd)DM Mean	T(DM) Mean +/- 2σ
LABRADORIAN PLUTONIC ROCKS									
ADLAVIK INTRUSIVE SUITE									
0241175	Gabbro, Main Body	1650	2.3	10.6	0.1455 +/- 73	0.512141 +/- 33	1.1 +/- 0.5	-4.3	2100 +/- 82
0241441	Gabbro, East Micmac	1650	4.5	25.4	0.1021 +/- 51	0.511299 +/- 38	-6.1 +/- 0.6	-11.6	2410 +/- 47
0249062	Gabbro, Pamiulik Pt.	1650	2.2	11.2	0.1142 +/- 57	0.511797 +/- 72	1.0 +/- 1.0	-4.4	1975 +/- 97
0249030	Diorite, Main Body	1650	5.0	26.9	0.1099 +/- 55	0.511684 +/- 36	-0.3 +/- 0.5	-5.7	2050 +/- 49
MOUNT BENEDICT INTRUSIVE SUITE									
0242136	Diorite	1650	7.5	40.1	0.1076 +/- 54	0.511649 +/- 40	-0.5 +/- 0.6	-5.9	2050 +/- 53
0242144	Syenite	1650	9.1	57.1	0.0949 +/- 47	0.511385 +/- 78	-2.9 +/- 1.1	-8.4	2170 +/- 84
GSZ 4	Quartz Syenite	1650	11.3	63.6	0.1039 +/- 52	0.511579 +/- 32	-1.0 +/- 0.5	-6.5	2080 +/- 41
MONKEY HILL INTRUSIVE SUITE									
AFZ 12	Monkey Hill Granite	1650	3.8	22.8	0.1063 +/- 53	0.511640 +/- 47	-0.4 +/- 0.7	-5.8	2050 +/- 60
0248191	Little Monkey Hill	1650	2.0	11.3	0.1093 +/- 55	0.511621 +/- 41	-1.4 +/- 0.6	-6.8	2125 +/- 55
OTHER UNITS									
AFZ 7	Witchdoctor Granite	1630	1.7	10.9	0.0933 +/- 47	0.511316 +/- 47	-4.2 +/- 0.7	-9.7	2225 +/- 51
0249074	Burnt Lake Granite	1630	3.1	17.4	0.1105 +/- 55	0.511537 +/- 33	-3.5 +/- 0.5	-9.0	2260 +/- 46
AFZ 8	Otter Lk.-Walker Lk.	1650	7.0	41.2	0.1021 +/- 51	0.511607 +/- 36	-0.1 +/- 0.5	-5.6	2010 +/- 45
UNCLASSIFIED, POSSIBLY LABRADORIAN PLUTONIC ROCKS									
AKZ 6	Stag Bay Granitoid	1725	12.2	70.3	0.1025 +/- 51	0.511604 +/- 61	0.7 +/- 0.9	-4.6	2025 +/- 72
0242030	Thunder Mtn Syenite	1725	12.1	66.1	0.1077 +/- 54	0.511633 +/- 66	0.1 +/- 0.9	-5.1	2077 +/- 83
LABRADORIAN VOLCANIC ROCKS									
0249324	Jagged Edge Area	1650	13.7	59.7	0.1371 +/- 69	0.512157 +/- 28	3.2 +/- 0.5	-2.2	1860 +/- 62
BR84187	Bruce River Group	1650	7.9	45.8	0.1014 +/- 51	0.511578 +/- 29	-0.5 +/- 0.4	-6.0	2040 +/- 37
"BASEMENT ROCKS" (Archean data from Brooks, 1983)									
ARCHEAN BASEMENT									
M1-AV	Layered Gneiss (n=3)	1650	3.9	26.0	0.0995 +/- 50	0.510697 +/- 55	-17.4 +/- 0.6	-22.8	3110 +/- 46
M2-AV	Layered Gneiss (n=2)	1650	4.1	23.6	0.1105 +/- 55	0.510910 +/- 21	-15.6 +/- 0.4	-21.0	3130 +/- 36
CAPE HARRISON METAMORPHIC SUITE									
AKZ-20	Tonalitic Gneiss	1850	5.8	35.4	0.0996 +/- 50	0.511623 +/- 70	0.7 +/- 1.0	-4.7	1950 +/- 80
AKZ-21	Granodiorite Gneiss	1850	3.2	18.1	0.1057 +/- 53	0.511639 +/- 48	-0.3 +/- 0.7	-5.7	2035 +/- 61

Table 8.7. Sm and Nd concentration and isotopic data for Labradorian plutonic and volcanic rocks, and basement rocks in the east and west at ca. 1650 Ma.

Details of initial Nd and model age calculations as for Table 8.6.

Two samples from the Monkey Hill Intrusive Suite have identical (within error) $\epsilon_{Nd}CHUR$ of 0 to -1.0, a surprisingly high value for siliceous leucogranites. The Witchdoctor and Burnt Lake Granites, despite lithological similarity to the above, have significantly lower $\epsilon_{Nd}CHUR$ of ca. -4.0. The Otter Lake - Walker Lake Granite has an approximate bulk-earth value. Kerr and Fryer (in press) report similarly neutral $\epsilon_{Nd}CHUR$ from two samples (including a biotite-muscovite leucogranite) correlated with this unit in the Nipishish Lake area, 100 km west of the study area.

The Bruce River Group sample has $\epsilon_{Nd}CHUR$ of ca. -0.5, also surprisingly high for a siliceous rhyolite. The Jagged Edge assemblage, if assumed to be of ca. 1650 Ma age, would have $\epsilon_{Nd}CHUR$ of +3.2. This is lower than its $\epsilon_{Nd}CHUR$ at 1810 Ma (see above), but is still higher than any Labradorian plutonic unit, including gabbros of the Adlavik Suite.

All Labradorian samples have negative $\epsilon_{Nd}DM$, and T_{DM} model ages are remarkably consistent at 2100 - 2000 Ma. Spatial variation in $\epsilon_{Nd}CHUR$ and T_{DM} is muted compared to that shown by Makkovikian units. The Monkey Hill Suite lies within the same area as older granitoid rocks with negative $\epsilon_{Nd}CHUR$, but clearly does not share their isotopic characteristics. In general, widely different Labradorian rock types show consistent initial Nd compositions -- a pattern that contrasts with the wide ϵ_{Nd} variations shown by Makkovikian intrusions with relatively constant compositional features.

Unclassified Plutonic Rocks

The Stag Bay Granitoid and Thunder Mountain Syenite have $\epsilon_{Nd}CHUR$ within 1 ϵ_{Nd} unit of bulk-earth values (0)
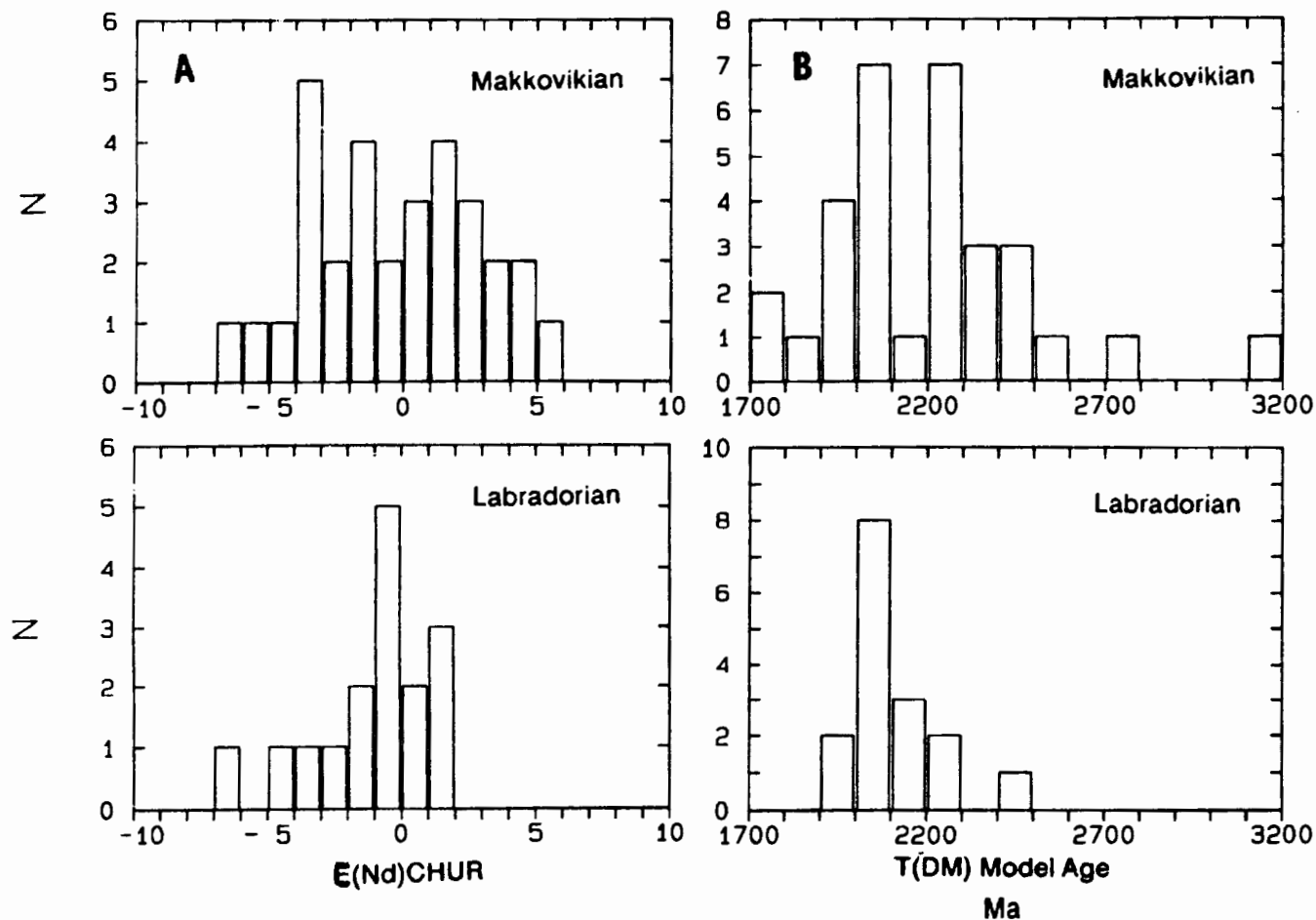
Figure 8.7. Histograms of ϵ_{Nd}CHUR and T_{DM} values for Makkovikian and Labradorian magmatic associations. Units of uncertain age are omitted from compilation.

for T = 1725 Ma. Changing their age to 1800 or 1650 Ma does not affect ϵ_{Nd} beyond the limits of analytical uncertainty. Values of this general magnitude are typical of some Makkovikian and most Labradorian plutonic rocks in the east of the area. In subsequent discussions, these unclassified units are arbitrarily grouped with the latter; in practice, their assignation has no impact on interpretation of results.

Spatial Variation in $\epsilon_{Nd}CHUR$ and T_{DM}

Geographic variation of $\epsilon_{Nd}CHUR$ and T_{DM} is illustrated in Figures 8.8 and 8.9. The western and eastern parts of the area are characterized by negative and positive $\epsilon_{Nd}CHUR$ respectively. The variation is shown most clearly by Makkovikian units. North of the Adlavik Brook fault zone, the generalized boundary between domains is in the vicinity of the Adlavik Islands, where there is a mixture of positive and negative values. South of the Adlavik Brook fault zone, the boundary must be further to the west, as Makkovikian Granitoids west of Big River have positive $\epsilon_{Nd}CHUR$. This dextral displacement of ca. 20-30 km is broadly equivalent to that indicated by outcrop patterns of granitoid and supracrustal units north and south of the Adlavik Brook fault zone (Chapter 2; Gower et al., 1982).

The simplest explanation of this variation is that the inversion line indicates the eastern limit of Archean crust in the Makkovik Province. The nature of the crust east of this line 's debatable (see later discussion), but it is, without doubt, significantly younger than Archean. A very similar variation pattern is indicated by the distribution of T_{DM} model ages (Figure 8.9). In both cases the inversion line is a sharp boundary, not a gradational one.
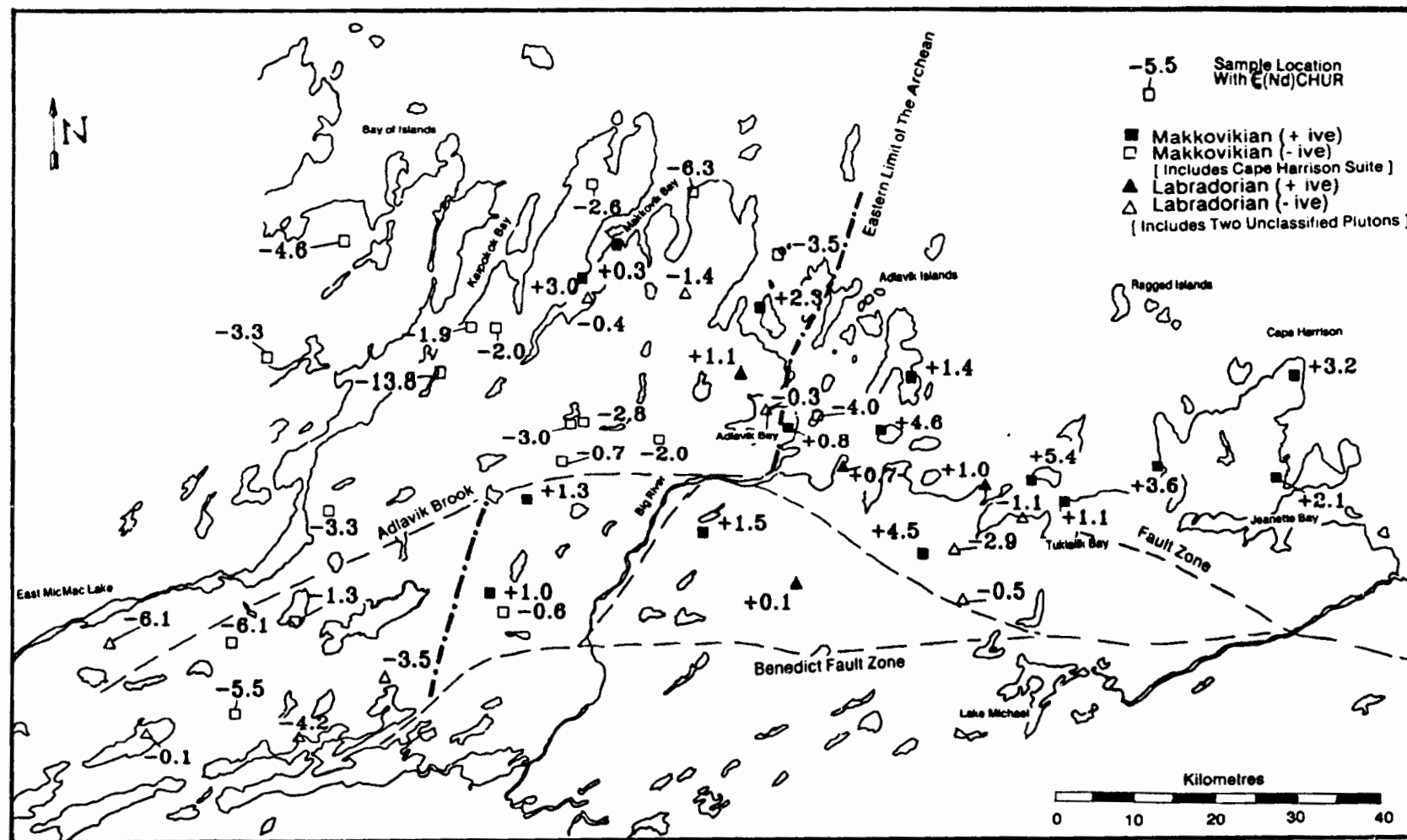
Figure 8.8. Spatial variation of ϵ_{Nd}CHUR in Makkovikian and Labradorian magmatic associations, showing the proposed eastern limit of Archean crust. Sample numbers are shown in Figure 8.4.
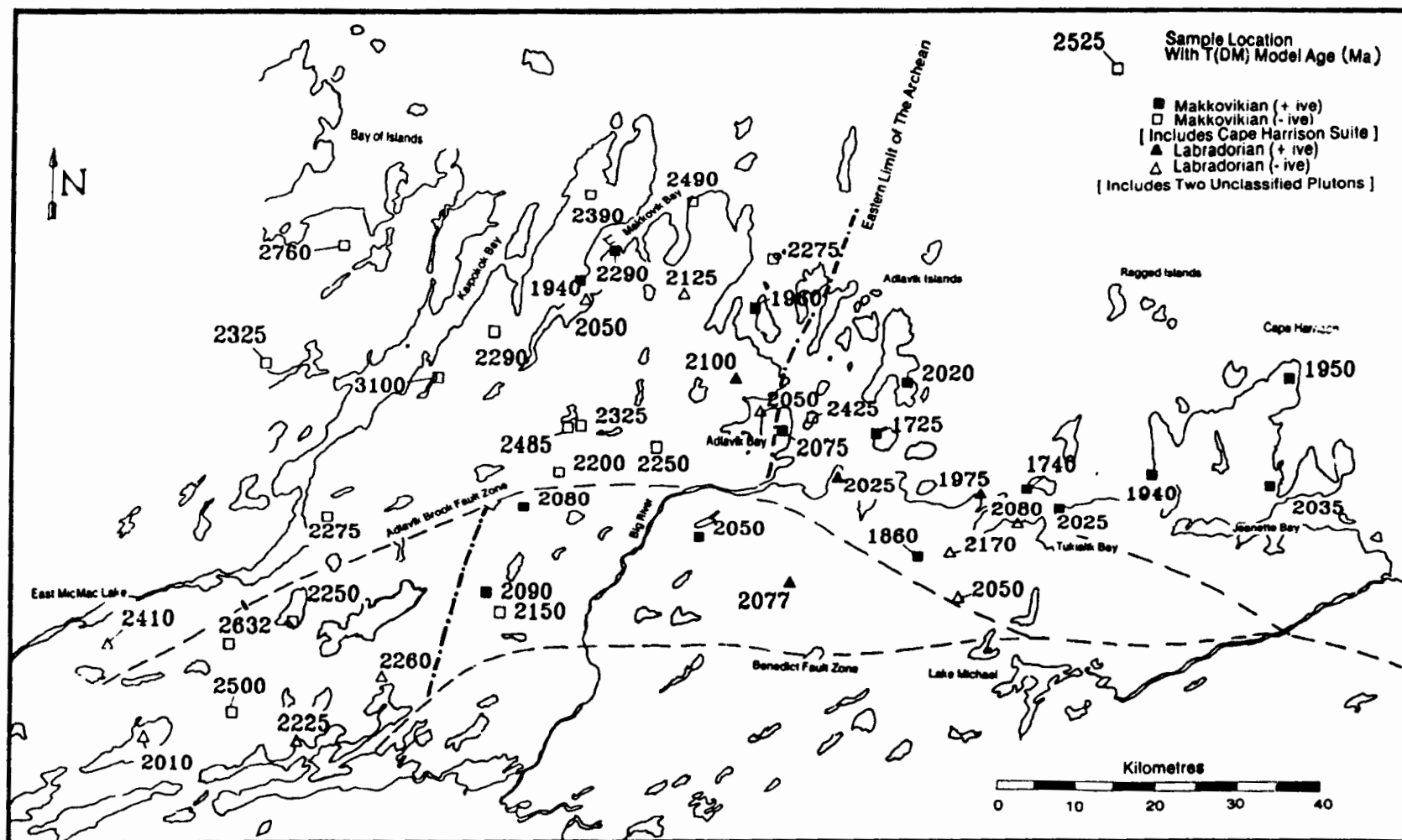
Figure 8.9. Spatial variation of T_{DM} in Makkovikian and Labradorian magmatic associations, showing the proposed eastern limit of Archean crust. Sample numbers are shown in Figure 8.4.

8.2.3 Nd Isotopic Trends and Contrasts

Trace element data discussed below are ICP-MS data
(MUN) determined on the sample splits used for Nd analysis
(see Appendix B; precision and accuracy estimates in
Appendix A). The Jagged Edge porphyry has been grouped
tentatively as Makkovikian (on the basis of high ϵ_{Nd}),
and Stag Bay and Thunder Mountain are included with
Labradorian units.

Major Element Patterns

ϵ_{Nd} is poorly correlated with major element
composition (Figure 8.10). The initial isotopic composition
of Labradorian units appears independent of major element
variation, except for a tendency towards slightly negative
$\epsilon_{Nd}CHUR$ at high SiO_2.

However, Makkovikian rocks show great variation in
$\epsilon_{Nd}CHUR$ at high SiO_2 contents. In the western domain
$\epsilon_{Nd}CHUR$ decreases with increasing SiO_2; this is a
common pattern in igneous suites, where siliceous
compositions usually contain a greater crustal component.
However, the increasing $\epsilon_{Nd}CHUR$ seen at high SiO_2
contents in the east is very unusual. It should be noted,
however, that this trend is imparted largely by samples
from the eastern Strawberry Suite and Jagged Edge
assemblage, and may not be typical of all units. Similar
antithetic behaviour of $\epsilon_{Nd}CHUR$ in Makkovikian rocks is
shown by correlations against FeO, Na_2O and N/N+K ratios,
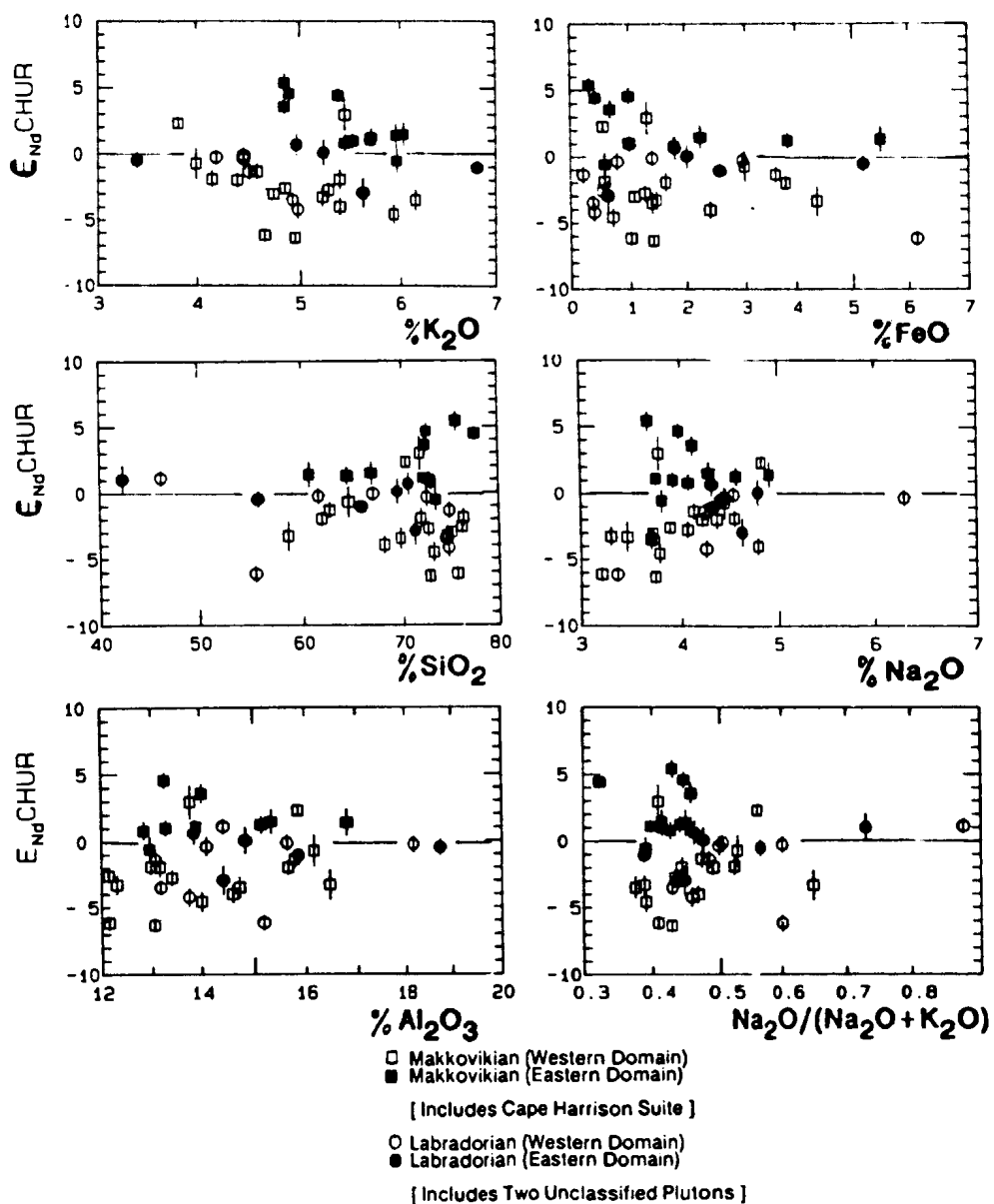but no correlation is present against Al_2O_3 and K_2O
(Figure 8.10).

Figure 8.10. Correlations between initial Nd isotopic composition (ϵ_{Nd}CHUR) and major element compositional variations.
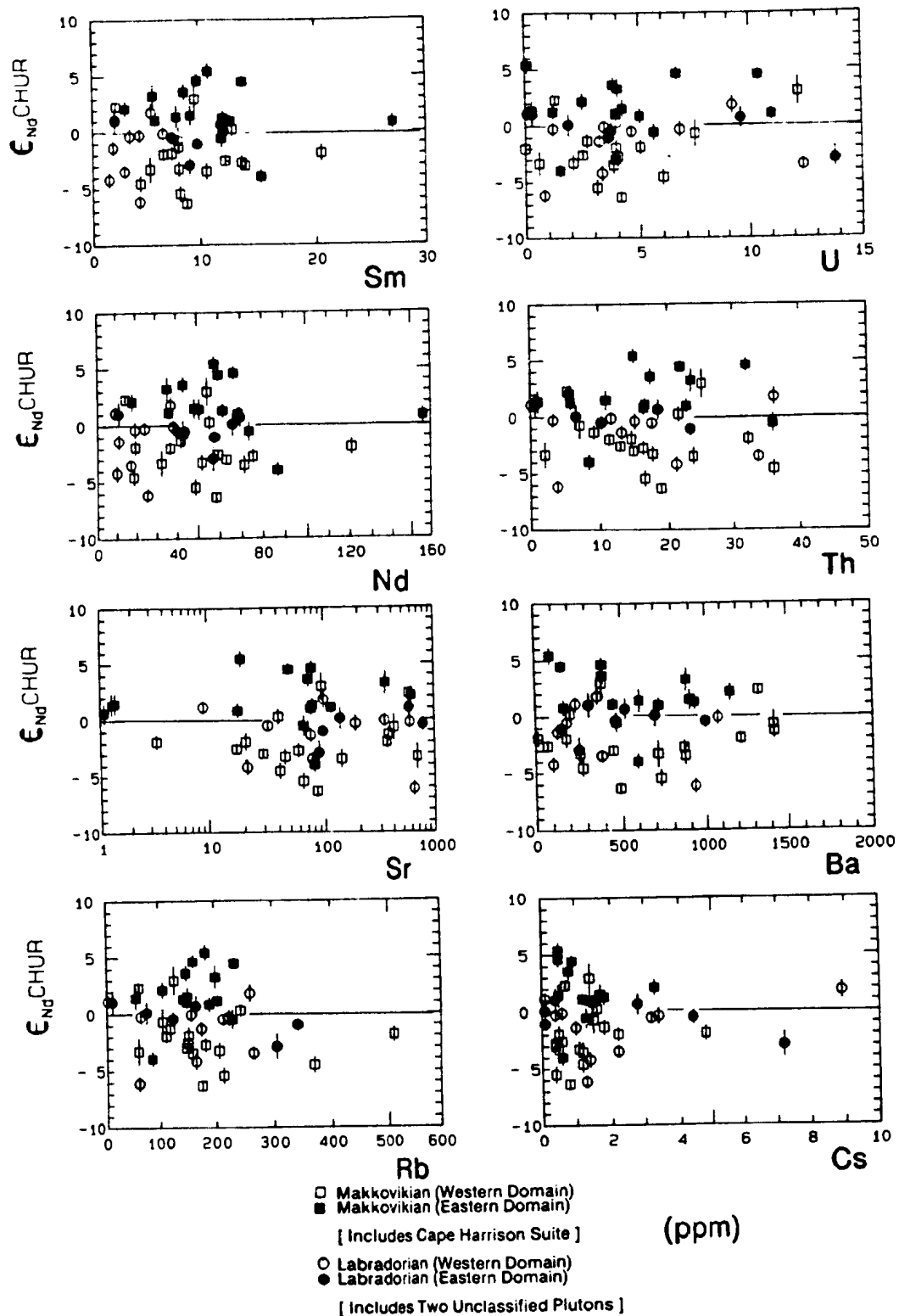
Figure 8.11. Correlations between initial Nd isotopic composition (ϵ_{Nd}CHUR) and trace element compositional variations.

Trace Element Patterns

There is no correlation between ϵ_{Nd} and either Nd or Sm (Figure 8.11). Trace elements which measure differentiation (e.g. Rb and Th; Figure 8.11) illustrate the same divergent behaviour as analogous major element parameters (e.g. SiO_2). In the east, $\epsilon_{Nd}CHUR$ increases with differentiation, whereas it decreases with differentiation in the west. In the western domain, there is a good inverse linear relationship between $\epsilon_{Nd}CHUR$ and Th, defined by the Long Island unit, Kennedy Mountain Intrusive Suite and western plutons of the Strawberry Suite. There are no obvious correlations between $\epsilon_{Nd}CHUR$ and these trace elements amongst Labradorian or unclassified rocks. Ba, Sr and Cs (Figure 8.11) show no clear patterns for either group.

Initial Ratio Trends

Initial Sr and Nd isotopic compositions are commonly inversely correlated in crustal rocks (e.g. DePaolo, 1981b; McCulloch and Chappell, 1982; Farmer and DePaolo, 1983; Wilson et al., 1985), and are commonly assessed via ϵ_{Nd} - ϵ_{Sr} diagrams, where hyperbolic trends are characteristic of mixing processes (e.g. Gray, 1984). This method cannot be used in this study due to the unreliability of whole-rock Sr data. However, "initial ratio isochron" diagrams where initial Nd compositions are plotted against $^{147}Sm/^{144}Nd$ ratios (Figure 8.12) should define linear trends in situations dominated by simple mixing, although such trends may be complicated by subsequent fractionation (Gray, 1984).
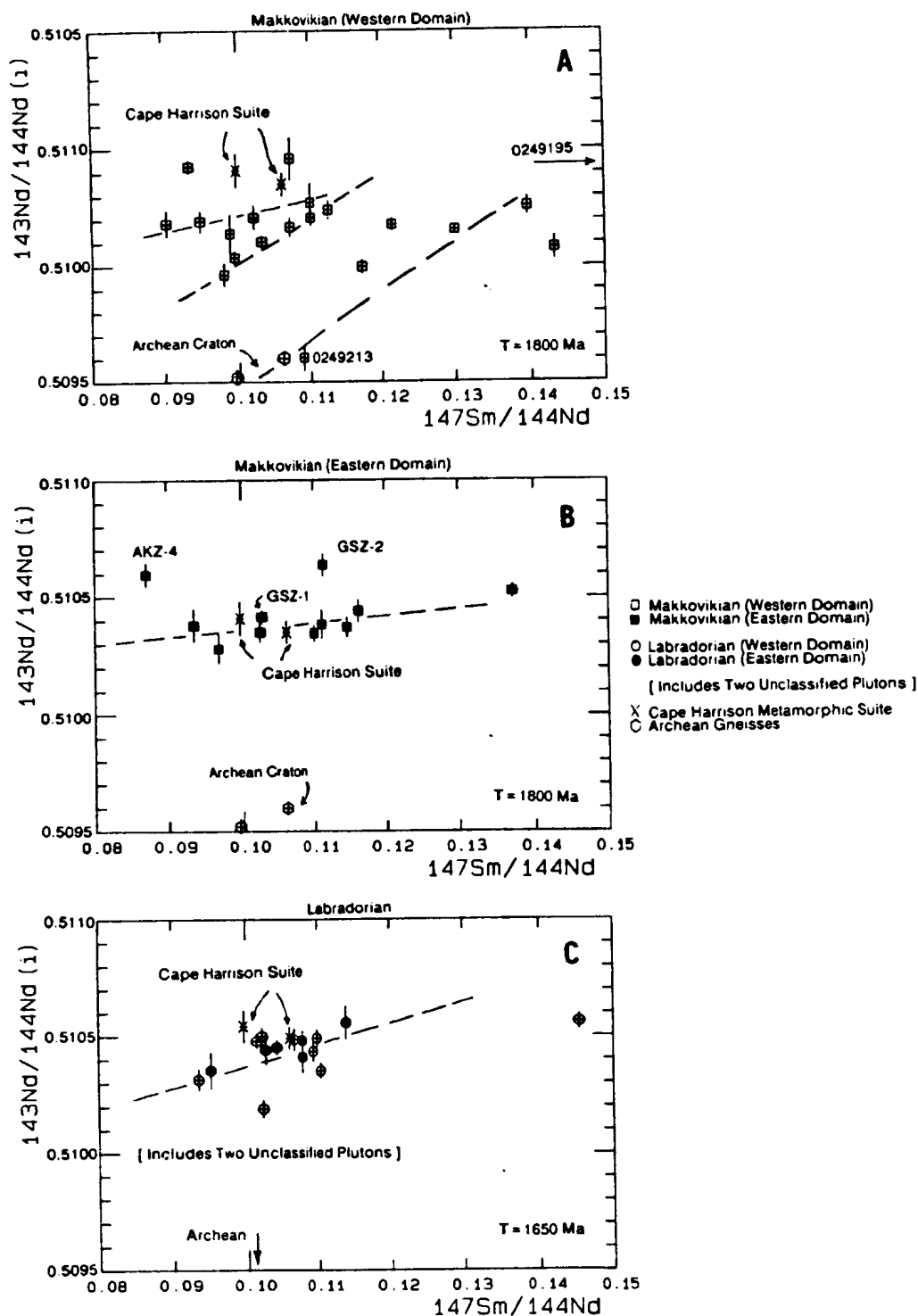
Figure 8.12. "Initial Ratio Isochron Diagrams" (after Gray,1984),
    showing initial $^{143}Nd/^{144}Nd$ versus $^{147}Sm/^{144}Nd$. (a)
    Makkovikian (eastern domain). (b) Makkovikian (western domain)
    (c) Labradorian and unclassified units (both domains). Lines a
    visual estimates of linear (mixing?) trends.

Makkovikian units in the eastern domain define a gently inclined to flat-lying array (Figure 8.12). Two samples from the Strawberry Intrusive Suite (AKZ-4; GSZ-2) lie well above this trend.

Makkovikian units in the western domain are scattered, but define linear subtrends (Figure 8.12); however, these trends do not correspond to petrological associations or suites. They are steeply inclined, and the Archean gneisses of Brooks (1983) plot close to the lower end of one feature.

Labradorian units mostly lie on a positive linear array (Figure 8.12); this has an orientation intermediate between those defined by Makkovikian units from eastern and western domains.

Linear trends of this type are consistent with (but not diagnostic of) two-component mixing relationships (e.g. Gray, 1984). If they have such a cause, the flat-lying trend of Makkovikian units in the east indicates similar ^{143}Nd/^{144}Nd for both end members, whereas the steep trends in the west indicate significant differences in their Nd isotopic composition. The disorganized pattern amongst Makkovikian units in the west suggests a complex mixing system with a variety of end-member compositions.

Note that the Cape Harrison Metamorphic Suite lies in the centre of the data array for Makkovikian (east) units, and cannot therefore strictly represent an end-member of a two-component system. However, any fractionation of Sm and Nd would move points along the trend to lower ^{147}Sm/^{144}Nd, so this is not an absolute constraint. The Cape Harrison Suite lies above the Labradorian array at T = 1650 Ma.

8.3 SUMMARY and DISCUSSION

This section is concerned mostly with the implications of Nd isotopic data, and also attempts to model the sources of Makkovikian and Labradorian magmas quantitatively.

8.3.1 The Unusual Case of The Pitre Lake Granite

Isotopic Evolution : The Pitre Lake Granite has $^{147}Sm/^{144}Nd$ (0.226) that is <u>higher</u> than accepted present-day values for CHUR (ca. 0.1966). It is evolving in the opposite direction (relative to CHUR) from most crustal rocks, i.e. its ϵ_{Nd}CHUR is <u>increasing</u> with time. Isotopic evolution of this granite is subparallel to postulated depleted mantle evolution, and its T_{DM} model age is infinite (Figure 8.13). These unusual features are demonstrated by its contrast with the anatectic Brumwater Granite, which evolves "normally" within the spectrum of its Archean precursors (Figure 8.13).

Fractionation of Sm and Nd : The high $^{147}Sm/^{144}Nd$ ratio indicates strong parent/daughter element fractionation during its generation. Such anomalous values have rarely been reported from crustal rocks.

Stevenson and Patchett (1988) attributed a similar value in an Archean leucogranite to garnet fractionation, but do not specify whether the anomalous granite is itself garnetiferous. Windrim et al.(1984) interpreted huge variations of $^{147}Sm/^{144}Nd$ and ϵ_{Nd} in sapphirine granulites in terms of pre-metamorphic hydrothermal
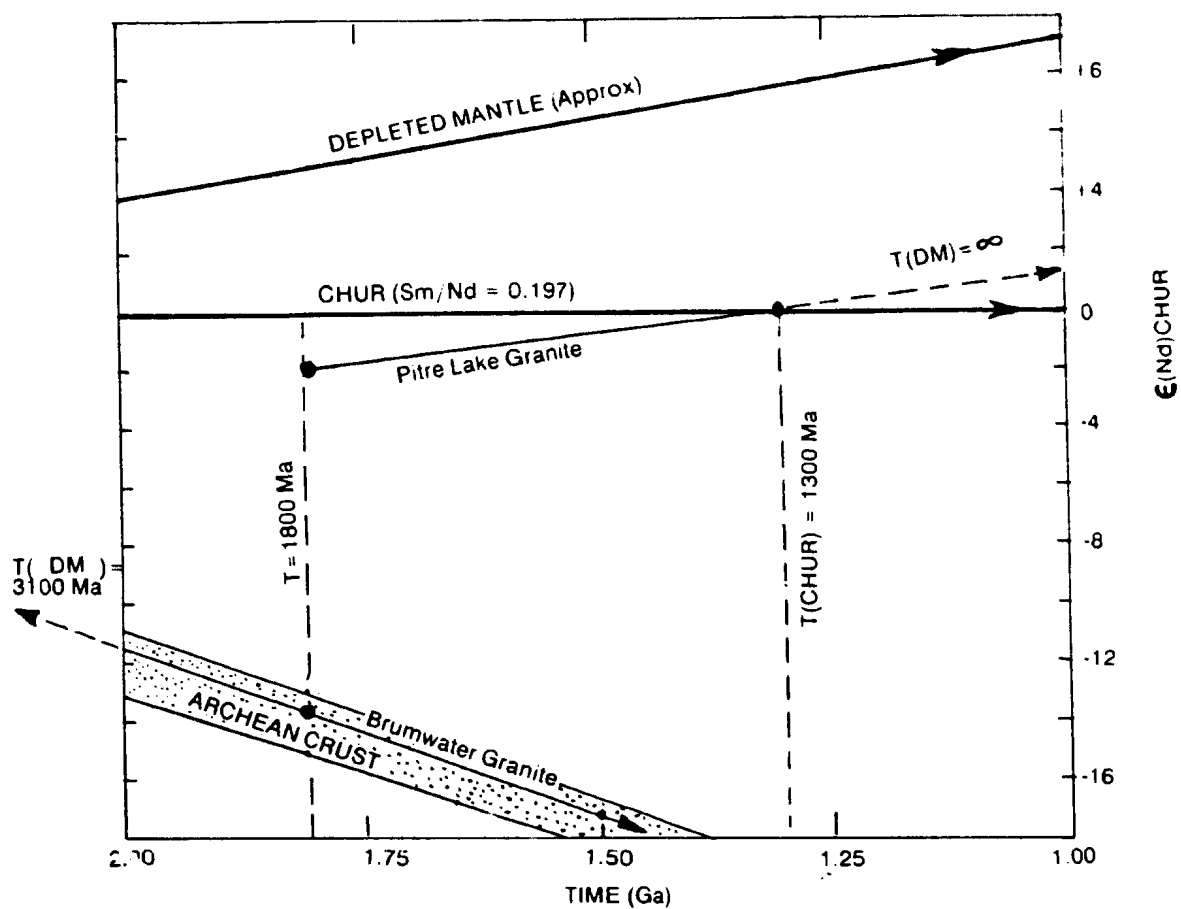
Figure 8.13. The unusual characteristics of the Pitre Lake Granite, compared to the relatively "normal" behaviour of the Brumwater Granite. Note that the Pitre Lake Granite evolves in the opposite direction (relative to CHUR) from most crustal rocks (compare to Figure 8.6).

processes. Unusual LREE-depleted geochemical patterns in Himalayan leucogranites have similarly been attributed to fluid activity (Vidal et al., 1982; Searle and Fryer, 1988)

The Pitre Lake Granite is not garnetiferous, and any residual garnet during anatexis would <u>decrease</u> Sm/Nd in an anatectic melt, based on distribution coefficients. Garnet fractionation could also not generate the unusual REE pattern of the granite (Figure 3.11, p.91). The normal behaviour of the adjacent Brumwater Granite, also of anatectic origin, argues against regional hydrothermal or metamorphic effects.

It is tentatively suggested that a residual accessory phase may have retained Nd during anatexis. Allanite and/or monazite are possible culprits, as both could strongly deplete partial melts in Nd (Miller and Mittlefehdlt, 1982; Michael, 1983). As no samples were collected from the metasedimentary rocks, this cannot be tested directly at present.

Source Characteristics : Regardless of subsequent evolution, the high ϵ_{Nd}CHUR of -1.9 indicates the characteristics of the source to the granite at 1800 Ma. This indicates a dearth of ancient Archean material in precursor metasediments, a surprising result in view of previous suggestions that they were deposited on local Archean Crust (Sutton, 1972). It may indicate that metasedimentary rocks of the Lower Aillik Group represent detritus from juvenile Proterozoic material, and/or a highly allochthonous setting for the sequence, which is everywhere separated from Archean basement by ductile slides (Marten, 1977).

Implications : Any discussion must remain speculative until the mineralogy and geochemistry of the metasedimentary precursors of the granite are better known. A detailed examination of Nd behaviour during anatexis of different components of the Kaipokok Bay fold belt is an interesting avenue for further work. Rocks such as the Pitre Lake Granite represent low melting-point components of the crust, and their importance as potential contaminants to other magmas (given time for isotopic evolution) outweighs their actual abundance. This example shows that crustal rocks do not invariably contrast strongly with the mantle in terms of Nd isotopic composition. It would also be interesting to test the equivalence of Moran Lake and Lower Aillik Group supracrustal sequences via their Nd isotopic compositions, which would record the proportion of Archean versus Proterozoic detritus in each.

8.3.2 Possible Sources of Makkovikian Magmas

Nature of Basement In The Makkovik Province

Variations in initial Nd isotopic composition indicate that Makkovikian rocks had different source material(s) in east and west (Figures 8.8; 8.9). Negative ϵ_{Nd}CHUR in the western domain indicates a contribution from older material, probably Archean continental crust. Generally positive ϵ_{Nd}CHUR in the eastern domain precludes a significant contribution from such material. Possible "basement" in the east (Cape Harrison Metamorphic Suite) is unlikely to be older than 2100 Ma, based on T_{DM} model ages (Table 8.6).

This striking geographic variation suggests that the isotopic features of Makkovikian magmas were influenced by the nature of local basement rocks, and implies that they were in part derived from such materials.

Continuity of elemental geochemical patterns from east to west, particularly amongst post-tectonic units, indicates that magmas in both domains had similar sources (and proportions thereof) in bulk compositional terms. For example, five plutons of the Strawberry Intrusive Suite have almost identical petrological and geochemical features, yet have a westward shift in $\epsilon_{Nd}CHUR$ from +5.0 to -6.0. If the western plutons contain a component derived from sialic crust, it follows that the eastern plutons also contain such material.

It is therefore concluded that the eastern Makkovik Province is underlain by sialic continental crust of Proterozoic age generated during pre-Makkovikian and/or Makkovikian episodes. The Cape Harrison Metamorphic Suite may represent some of this material; however, as discussed below, it does not fulfill all isotopic requirements.

The inferred edge of the Archean Craton is offset dextrally by the Adlavik Brook fault zone (Figures 8.8, 8.9). Taken at face value, this indicates a major structure that extends through the continental crust. However, as the fault zone was active during the Grenvillian orogeny, the apparent displacement may only be in the upper levels of the crust -- i.e., intrusions may no longer be above their original source regions.

Sources of Makkovikian Magmas

Western Domain : Low $\epsilon_{Nd}CHUR$ and high T_{DM} in the west indicate contributions from older crust. The most extreme example is the Brumwater Granite, which is

isotopically indistinguishable from the Archean (Table 8.6; Figure 8.13), and was probably derived entirely by anatexis of this material. Most other units in the west, however, have higher ϵ_{Nd}CHUR than the Archean gneisses would have at 1800 Ma.

It is suggested here that they are mixtures of juvenile mantle-derived material and older continental crust. An alternative explanation is that they were derived by anatexis of continental crust generated at a variety of times between 2600 and 2000 Ma ago (c.f. McCulloch and Chappell, 1982). This is considered unlikely, as there is no evidence of orogenic activity during this period in Labrador, or on a worldwide scale (Patchett and Arndt, 1986). Mantle-crust interaction during granitoid magmatism was suggested by DePaolo (1981b) in the western U.S.A, and by Halliday (1984) in the British Caledonides. However, the initial ratio isochron diagram for the western domain (Figure 8.12) suggests that there is no simple two-component mixing system in this area.

In view of the lithogical and structural complexity of the Archean Nain Province, this is not unexpected. The ϵ_{Nd}CHUR of the Brumwater Granite (ca. -14.0) indicates that, at least locally, values calculated from the data of Brooks (1983) are representative, but anatexis commonly samples the lowest melting-point compositions within its precursor. The Archean of the Hopedale area also includes extensive tonalitic and trondhjemitic granitoid rocks of ca. 2800 Ma age (Loveridge et al., 1987), and a range of Archean supracrustal rocks. These would all have different Sm/Nd ratios and ϵ_{Nd}CHUR values at 1800 Ma, and cannot therefore be represented as a point-source in a mixing diagram.

Eastern Domain : Units in the eastern domain define a linear initial ratio trend that is almost flat-lying (Figure 8.12). This is consistent with simple mixing of two components with similar $^{143}Nd/^{144}Nd$, but different $^{147}Sm/^{144}Nd$. It is suggested here that these magmas were mixtures between a "juvenile" component and slightly older Proterozoic sialic crust perhaps represented by material such as the Cape Harrison Metamorphic Suite. The well-defined linear trend suggests a simpler system, possibly with only two end-members. Two samples from eastern plutons of the Strawberry Suite (e.g. AKZ-4, GSZ-2) lie above this trend, but a third (GSZ-1) lies within it. These units may therefore have had somewhat different sources.

Crust-Mantle Mixing Models

Methodology : The proportion of continental crust (X) added to one part of a more juvenile magma to form new crust is given by the simplified expression :

$$X = \frac{C_{Nd}(JV) \ [\ \epsilon_{Nd}(NC) - \epsilon_{Nd}(JV) \ ]}{C_{Nd}(CC) \ [\ \epsilon_{Nd}(CC) - \epsilon_{Nd}(NC) \ ]}$$

where JV = juvenile component, NC = new crust, CC = crustal component, and C_{Nd} = Nd concentration (Pushkar et al., 1972; Patchett and Bridgwater, 1984; Chauvel et al., 1987). The percentage of crustal component is given simply by $100X / (1 + X)$. Results depend heavily on Nd concentrations in the end-members; in the case of the juvenile component, these are difficult to constrain. An upper limit to its ϵ_{Nd}CHUR is provided by depleted mantle at ca. 1800 Ma

(+5.0; Nelson and DePaolo, 1984; Patchett and Bridgwater, 1984). However, modern island-arc magmas commonly have slightly lower ϵ_{Nd} than inferred depleted mantle compositions (e.g. White and Patchett, 1984). The Nd content of a mantle-derived basalt to andesite magma could range from 5 to 20 ppm, based on modern island arcs (White and Patchett, 1984). A Nd content of 25 ppm is assumed for the crustal component, based on data from Brooks (1983). This is slightly lower than estimated mean values for sialic crust based on composite samples (e.g. Patchett and Bridgwater, 1984).

Results : Due to the difficulty in constraining end-members, model results are given as matrices (Table 8.8), which give the percentages of crustal material required to generate a specific final ϵ_{Nd}CHUR value. The parameters of crustal end-members are based on the Archean gneisses and Cape Harrison Suite in west and east respectively; the average ϵ_{Nd}CHUR of the former is increased to -12.0, to account for younger (2800 Ma) material within it. . It is assumed that the juvenile magma had ϵ_{Nd}CHUR of +5.0. All are conservative estimates which, if anything, will <u>overestimate</u> the proportion of crustal material required.

For a value of 10 ppm Nd in the juvenile component (c.f. Patchett and Bridgwater, 1984), a typical Makkovikian magma in the west must include from 26% (final ϵ_{Nd}CHUR = -3.0) to 42% (final ϵ_{Nd}CHUR = -6.0) Archean crust (Table 8.8a). The proportion of Archean material required varies in sympathy with the Nd concentration in the juvenile component. In the eastern domain, equivalent amounts of mixing using Cape Harrison material as "crust" would reduce ϵ_{Nd}CHUR by less than two ϵ_{Nd} units (Table 8.8b).

A

WESTERN DOMAIN (Archean Continental Crust)

€(Nd)CHUR of Crustal Component = -12.0 (Conservative)
€(Nd)CHUR of Juvenile Component = +5.0 (Depleted Mantle)
Concentration of Nd in Crustal Component = 25 ppm

Final ϵ(Nd)CHUR Value	Concentration of Nd in Juvenile Component						
	5 ppm	7.5 ppm	10 ppm	15 ppm	20 ppm	25 ppm	
+5	0	0	0	0	0	0	
+4	1	2	2	4	5	6	
+3	3	4	5	7	10	12	
+2	4	6	8	11	15	18	
+1	6	8	11	16	20	24	
0	8	11	14	20	25	29	
-1	10	14	18	25	30	35	
-2	12	17	22	30	36	41	Percentage Of
-3	15	21	26	35	42	47	Crustal Component
-4	18	25	31	40	47	53	Required
-5	22	30	36	46	53	59	
-6	27	35	42	52	59	65	
-7	32	42	49	59	66	71	
-8	39	49	57	66	72	76	
-9	48	58	65	74	79	82	
-10	60	69	75	82	86	88	
-11	76	83	86	91	93	94	
-12	100	100	100	100	100	100	

B

EASTERN DOMAIN (Juvenile Proterozoic Continental Crust)

€(Nd)CHUR of Crustal Component = +2.0 (Cape Harrison Suite)
€(Nd)CHUR of Juvenile Component = +5.0 (Depleted Mantle)
Concentration of Nd in Crustal Component = 25 ppm

Final ϵ(Nd)CHUR Value	Concentration of Nd in Juvenile Component						
	5 ppm	7.5 ppm	10 ppm	15 ppm	20 ppm	25 ppm	
+5.0	0	0	0	0	0	0	
+4.5	4	6	7	11	14	17	
+4.0	9	13	17	23	29	33	Percentage Of
+3.5	17	23	29	38	44	50	Crustal Component
+3.0	29	38	44	55	62	67	Required
+2.5	50	60	67	75	80	83	
+2.0	100	100	100	100	100	100	

Table 8.8. Two-component mixing matrices for Makkovikian magmas, showing percentages of crustal component required to generate a specific final ϵ_{Nd}CHUR value. (a) Western domain (Archean Crust). (b) Eastern Domain (Proterozoic Crust).

These are model-dependant results, and no unique solution is possible. However, the amounts of mixing required in the west are reasonable for combined assimilation - fractional crystallization (DePaolo, 1981a), and it is clear that equivalent interaction in the east would be very difficult to recognize isotopically, particularly if the Nd content of the juvenile component was lower, or its ϵ_{Nd}CHUR higher than postulated.

However, eastern plutons of the Strawberry Intrusive Suite have higher ϵ_{Nd}CHUR than permitted if they incorporate significant amounts even of Cape Harrison-type materials. Any crustal component in these rocks must have a minimal crustal prehistory. Three samples in the east also have ϵ_{Nd}CHUR values that are equivalent to or slightly below those for the Cape Harrison Metamorphic Suite at 1800 Ma, but within analytical error of these rocks. If this difference is real, it may indicate that material with lower ϵ_{Nd}CHUR than the Cape Harrison Suite also contributed some material to the magmas.

8.3.3 Possible Sources Of Labradorian Magmas

Continuity of Isotopic Compositions

Labradorian suites show less variation in ϵ_{Nd}CHUR (Table 8.7), and show no strong geographic variation (Figure 8.8). With the exception of three samples in the west, most have values close to those of CHUR (0), regardless of their composition or location. There are, however, some slightly negative ϵ_{Nd}CHUR values in the Benedict Mountains area (see below).

Similar observations were made by Patchett and Bridgwater (1984) and Patchett and Kouvo (1986), who found

that a wide range of Proterozoic igneous rocks in Greenland
and Finland also clustered around approximate bulk-earth
ϵ_{Nd}CHUR values (ca. 0).

Sources Of Labradorian Magmas

Processes which could account for ϵ_{Nd}CHUR values of
ca. 0 include derivation from an undepleted mantle
reservoir or melting of slightly older continental crust.
In terms of the study area, the first appears unlikely in
view of direct evidence for depleted source materials in
Makkovikian granitoid rocks. The second cannot be ruled out
for granites (s.s), as the Cape Harrison Metamorphic Suite
and some Makkovikian rocks in the east would have ϵ_{Nd}CHUR
of ca. 0 at 1650 Ma, and some have similar T_{DM} to the
Labradorian samples. However, it is difficult to visualize
a partial melting process that could generate mafic and
intermediate magmas of the Adlavik and Mount Benedict
Intrusive suites from such materials; these must surely be
derived from mantle materials. Also, the ϵ_{Nd}CHUR of
Makkovikian rocks in the western domain indicates that some
Makkovikian crust in this part of the area would have had
ϵ_{Nd}CHUR of -4.0 to -8.0 at 1650 Ma.

A third alternative is that Labradorian magmas are
mixtures of juvenile material and older crust -- but in
relatively constant proportions. Patchett and Bridgwater
(1984) and Patchett and Kouvo (1986) preferred this
alternative in their studies, and suggested that mixing and
homogenization of end-members was achieved by subduction of
continent-derived sediment into zones of mantle melting.
Observed compositional variation was then produced by
fractionation and remelting of this material in the crust.

In general terms, this model appears to be applicable
to Labradorian plutonic rocks, but it should be noted that

the role of subducted sediment in arc magmatism has been questioned (e.g. Pankhurst et al., 1988; Hildreth and Moorbath, 1988; see chapter 9). Distal (subcrustal?) mixing is also consistent with the lack of evidence for direct contributions from local Archean basement rocks, and with the constancy of ϵ_{Nd}CHUR across the Labradorian compositional spectrum.

The Witchdoctor and Burnt Lake Granites, however, contain greater amounts of an older component. These could incorporate local Archean basement material or, alternatively, could be anatectic melts derived from Makkovikian granitoid rocks. However, they lie on a well-defined initial ratio isochron with other Labradorian samples (Figure 8.12), suggesting that they may simply be part of the same mixing spectrum.

Mixing and Contamination Models

Mixing calculations for Labradorian magmas are summarized in Table 8.9a. Using ϵ_{Nd}CHUR = +5.5 and 10 ppm Nd for juvenile mantle-derived material, and -12.0 and 25 ppm respectively for the crustal component (c.f. Patchett and Bridgwater, 1984; 8.3.2), a Labradorian magma with final ϵ_{Nd}CHUR of 0 must contain ca. 15% crustal material. This is geologically reasonable, and similar to estimates of the sedimentary component in some modern arc magmas (White and Patchett, 1984). It is also a reasonable proportion for direct assimilation but, as discussed above, such an explanation requires that gabbro and leucocratic granites both contain the same proportions of assimilated crust, which is unlikely.

Variation of ϵ_{Nd}CHUR in the Adlavik and Mount Benedict Suites is treated in the same manner to assess contamination by crustal material (Table 8.9b). The

Labradorian Plutonic Rocks (General)						A

ϵ(Nd)CHUR of Crustal Component = -12.0 (Conservative)
ϵ(Nd)CHUR of Juvenile Component = +5.5 (Depleted Mantle)
Concentration of Nd in Crustal Component = 25 ppm

Final ϵ(Nd)CHUR Value	Concentration of Nd in Juvenile Component						
	5 ppm	7.5 ppm	10 ppm	15 ppm	20 ppm	25 ppm	
+5	0	1	1	2	2	3	
+4	1	3	4	5	7	9	
+3	2	5	6	9	12	14	
+2	2	7	9	13	17	20	
+1	3	9	12	17	22	26	
0	4	12	15	22	27	31	
-1	6	15	19	26	32	37	
-2	7	18	23	31	38	43	Percentage Of
-3	9	22	27	36	43	49	Crustal Component
-4	11	26	32	42	49	54	Required
-5	13	31	38	47	55	60	
-6	16	37	43	53	61	66	
-7	20	43	50	60	67	71	
-8	25	50	57	67	73	77	
-9	33	59	66	74	79	83	
-10	44	70	76	82	86	89	
-11	62	83	87	91	93	94	
-12	100	100	100	100	100	100	

Contamination Of Adlavik and Mount Benedict Intrusive Suites						B

ϵ(Nd)CHUR of Crustal Component = -12.0
ϵ(Nd)CHUR of Parental Magma = +1.0 (Adlavik Gabbro)
Concentration of Nd in Crustal Component = 25 ppm

Final ϵ(Nd)CHUR Value	Concentration of Nd in Parental Magma						
	5 ppm	7.5 ppm	10 ppm	15 ppm	20 ppm	25 ppm	
+1.0	0	0	0	0	0	0	
+0.5	1	1	2	2	3	4	
0.0	2	2	3	5	6	8	
-0.5	3	4	5	7	9	12	
-1.0	4	5	7	10	13	15	Percentage Of
-1.5	5	7	9	13	16	19	Crustal Component
-2.0	6	8	11	15	19	23	Required
-2.5	7	10	13	18	23	27	
-3.0	8	12	15	21	26	31	
-3.5	10	14	17	24	30	35	
-4.0	11	16	20	27	33	38	
-4.5	13	18	23	31	37	42	
-5.0	15	20	26	34	41	46	

Table 8.9. Two-component mixing matrices for Labradorian magmas, showing percentages of crustal component required to generate a specific final ϵ_{Nd}CHUR value. (a) General crust-mantle mixtures. (b) Contamination of Adlavik or Mount Benedict Suite mafic magma by Archean crust.

ϵ_{Nd}CHUR of the parental magma is taken to be +1.0 (based on Adlavik Suite gabbro), considered to be a signature acquired prior to emplacement. If it had 10 ppm Nd, such a magma must assimilate a further 10-15% of crustal material (ϵ_{Nd}CHUR = -12.0) to obtain a final value of -2.0 to -3.0 in the most differentiated material. This proportion is substantially reduced (< 7.5%) if the Nd content of the parent magma was below 10 ppm, or if the contaminant actually had ϵ_{Nd}CHUR of ca. -17.0, which is the calculated value for Archean gneiss (Brooks, 1983) at 1650 Ma (Table 8.7). Contamination effects also explain the negative (ca. -6) ϵ_{Nd}CHUR of the gabbro at East Micmac Lake in the western domain, which also has a higher SiO_2 than gabbro in the west. The amount of Archean material required to generate this value, however, is over 30%, assuming 10 ppm Nd for the juvenile magma (Table 8.9). This unreasonable figure is reduced significantly if the conditions discussed above applied here also.

Only Archean crustal material is a viable contaminant for Adlavik and Mount Benedict Suite magmas; however, the latter lies well east of the edge of the Archean craton as inferred from Makkovikian data (Figures 8.8;8.9). It is, however, unlikely that this crustal boundary is a simple vertical interface. The signatures of Makkovikian granitoid rocks probably reflect their partial lower crustal sources, whereas contamination of the Mount Benedict Suite probably took place in the upper crust, which may have contained some Archean or Archean-derived material. The presence of some upper crustal Archean material would also explain the mixture of positive and negative ϵ_{Nd}CHUR values along the proposed boundary (Figure 8.8), and anomalously low ϵ_{Nd}CHUR at the border of the Numok Intrusive Suite, close to the proposed boundary (Sample AKZ-3; Table 8.6).

CHAPTER NINE
A COMPARATIVE ANALYSIS

Chapter Abstract

In order to evaluate the affinities and possible tectonic
settings of the TLGB Makkovikian and Labradorian plutonic
assemblages, a quantitative comparative analysis was attempted.
This employs published and unpublished data from several
granitoid batholiths taken to represent specific tectonic
environments.

Volcanic-arc batholiths are represented by data from Mesozoic
to Cenozoic, circum-Pacific batholiths of Peru, Chile and
southern California. All are associated with active or
recently active zones where oceanic crust is subducted beneath a
continental margin. Collisional environments representing later
stages of orogenesis are represented by Cenozoic granitoid rocks
from the Himalayan belt of Afghanistan, and by the late- to
post-orogenic Paleozoic granites of the Newfoundland
Appalachians. The latter assemblage probably represents the most
complete sampling of the later magmatic products of orogeny.
Within-plate granitoid batholiths are represented by Middle
Proterozoic granitoid rocks from northern Labrador, which are
closely similar in petrology to Phanerozoic anorogenic suites.
Large amounts of generally representative data are available from
most of these areas. This allows the use of extensive parameters
such as frequency spectra, abundance of rock types and
evolutionary trends as comparative tools, in addition to
conventional intensive methods such as discrimination diagrams.

The Makkovikian assemblage contrasts very strongly with
volcanic arc batholiths. Specifically, it is characterized by
enrichment in SiO_2, K_2O, Na_2O, K+N/A, F/F+M, and depletion
of MgO, CaO and N/N+K. It is compositionally restricted in
comparison to the broad, expanded spectrum of arc compositions.
Although most major element frequency spectra resemble the
Newfoundland assemblage, Makkovikian granites are significantly
more agpaitic and Fe-enriched at all SiO_2 contents. Such
features suggest that they are transitional towards within-plate
assemblages such as Flowers River, which has similar, but more
extreme, tendencies in these directions. Compositional evolution
in the Makkovikian assemblage follows a "quartz-poor" trend via
monzonite and syenite, that is distinct from the "quartz-rich"
(via granodiorite and monzogranite) trend of the Newfoundland
granites. Trace element data indicate enrichment in Zr, Y, F and
REE relative to Newfoundland, but not to levels typical of
Flowers River. The Makkovikian assemblage falls in within-plate
granite or A-type granite fields in trace element discrimination
plots.

It is suggested that a post-orogenic, possibly
post-collisional, affinity is more consistent with the geological
setting of the Makkovikian assemblage than an anorogenic
environment. It is clear, however, that the Makkovikian
assemblage has many features that are akin to granites generated
in such settings. These differences require explanation in any
tectonic model incorporating a post-collisional setting for these
granitoid magmas (see Chapter 10).

The Labradorian assemblage is difficult to classify via
geochemical comparisons, partly because it is only the northern
fringe of a much wider belt, and may not represent its full
compositional anatomy. It includes a range of compositions
similar to those of volcanic-arc batholiths, but has a bimodal
compositional spectrum, and is generally more siliceous and
potassic. Labradorian granitic rocks have some tendencies towards
Fe-enrichment and high K+N/A, but not to the same degree as the
Makkovikian assemblage. They do not show the distinctive trace
element signatures of Makkovikian granites, and could belong to
either arc or collisional assemblages. The Labradorian assemblage
falls mostly in the volcanic-arc or I-type granite fields on
trace element discrimination plots. Labradorian mafic and
intermediate rocks, as discussed in Chapter 5, have affinities to
high-K calc-alkaline or shoshonitic associations, and fall
dominantly in the calc-alkaline basalt field in trace element
discrimination plots.

A distal portion of a magmatic arc (i.e. well removed from
the locus of subduction) is one possible setting for Labradorian
magmatism. This is consistent with its siliceous and potassic
character relative to proximal volcanic-arc batholiths, and the
lack of a recognisable Labradorian "orogeny" in the study are
could be then attributed to great distance from the main orogenic
belt. However, similar assemblages also occur in post-orogenic,
post-collisional settings, where granite compositions overlap
partly with those of mature or distal arcs. At the present time,
it is difficult to select between these alternatives. However,
the Nd isotopic signatures of Labradorian mafic rocks favour an
arc environment, and there are obvious contrasts between
Labradorian granites and the categorically post-orogenic
Makkovikian assemblage.

Introduction

This chapter assesses TLGB magmatic assemblages with reference to Proterozoic and Phanerozoic assemblages that represent diverse environments of granitoid magmatism.

This comparative analysis is presented partly in terms of their compositional spectra and evolutionary trends, combined with traditional methods based on intensive parameters such as major and trace element abundances. Kerr (in press) presents a preliminary analysis of this nature, for the TLGB, which was completed prior to the recognition of discrete post-tectonic Makkovikian and Labradorian assemblages. The following discussion employs a wider selection of comparative data, and revises some earlier conclusions in the light of this improved geochronological framework.

Genetic and/or tectonic classifications of granitoid rocks are a veritable "growth industry" in petrology. Current mainstream viewpoints concerning environments and classification of granitoid magmatism are reviewed in Chapter 1.

Spectral Analysis of Granitoid Batholiths

Phanerozoic granitoid magmatism forms a compositional continuum, and unique rock types characteristic of specific environments do not exist. Furthermore, diverse tectonic environments are likely to be spatially and/or temporally superimposed in ancient orogenic belts. This reality poses formidable problems in classification, particularly when conclusions are based on small numbers of data that represent restricted areas or time-slices in the history of a belt, as is normally the case.

Modern geochemistry emphasizes _intensive_ parameters
such as element abundances or REE patterns as
classification tools (e.g. Pearce et al., 1984). An
alternative approach is to use _extensive_ parameters such as
frequency spectra, proportions of rock types and
geochemical changes with space, time and differentiation.
"Spectral analysis" of this type is not a new concept (e.g.
Martin and Piwinski, 1972; Petro et al., 1979), but it has
not been widely applied.

Spectral analysis methods require large, statistically
representative, geochemical databases, such as the
information presented here for the TLGB. Such information
is increasingly available (e.g. the ARTEMISE data bank,
maintained by CNRS in France; Leterrier et al., 1983) and,
coupled with unpublished data available to the author,
allows an analysis of this type to be attempted here. There
are, naturally, difficulties in assessing the degree to
which such data represents specific environments, and some
potential problems in comparing trace element data of
variable quality from different sources. However, these
problems are also inherent in trace element discrimination
schemes based on intensive parameters.

9.1 OVERVIEW OF COMPARATIVE GEOCHEMICAL DATA

Seven comparative geochemical databases were assembled
(Table 9.1). A brief description of each is presented
below, and any problems in interpretation or use of these
data are noted. Wherever possible, tectonic environments
have been duplicated, to allow a parallel assessment of
variations in the character of a single setting. Note that
the TLGB data used in comparisons conprise the regional
(grid-based) sample population only, and that unclassified
plutonic rocks and all volcanic rocks are excluded.

Area and Source(s)	Age and Setting	Area [sq.km]	Number Analyses	Density	Trace Element Analysis Suite	Comments
Trans-Labrador Granitoid Belt [This Study]	Makkovikian Assemblage	8,500	511	1/10 km2	F Be Li V Cr Co Ni Cu Zn Ga Rb Sr Y Zr Nb Mo Sn Ba La Ce W Pb Th U	Samples from regional grid population only, excluding all unclassified and volcanic rocks.
	Labradorian Assemblage		332	1/10 km2		
Coastal Batholith Of Peru [Pitcher et al.,1985]	Mesozoic Magmatic Arc Batholith	80,000	217	n/a	Sc V Cr Co Ni Cu Zn Ga Rb Sr Y Zr Nb Cs Ba La Ce Hf Pb Th U	Traverse-based sampling. Trace element coverage is heterogeneous.
Mesozoic Batholiths Of North-Central Chile [Brown, pers.comm.]	Mesozoic Magmatic Arc Batholith	12,000	280	1/40 km2	V Cr Co Ni Cu Zn Ga Rb Sr Y Zr Nb Ba La Ce Pb Th U	Setting is analogous to Peru. Generally representative of all rock types areally. Homogeneous trace element data.
Batholithic Rocks Of Southern California [Baird and Miesch, 1984]	Mesozoic Magmatic Arc Batholith	20,000	482	1/40 km2	major elements only	Grid-based sampling used in multivariate statistical model. Numerous other studies of batholith are published.
Alpine-Himalayan Plutonic Belts Of Afghanistan [Debon et al.,1987a,b]	Mesozoic To Cenozoic Collisional Orogen	> 100,000 [estimates very approximate]	670	1/100 km2	V Cr Co Ni Cu Rb Sr Ba	Size of study precludes estimation of sampling density. Poor detection limits for Cr, Co, Ni.
	Cenozoic Only [Collisional]		334	-	-	Peraluminous biotite-muscovite leucogranites and coeval metaluminous granitoid rocks.
	Mesozoic Only [Magmatic Arcs?]		336	-	-	Polyphase tonalite-granodiorite-granite batholiths
Post Taconic Granitoid Rocks Of The Newfoundland Appalachians Strong et al., 1974; Dept. of Mines, Unpublished Data	Middle Paleozoic Syn- and Post-Collisional Batholiths [Excludes Ordovician Arc Granitoids]	ca. 30,000	1202	1/25 km2	F Be Li V Cr Co Ni Cu Zn Ga Rb Sr Y Zr Nb Mo Sn Ba La Ce W Pb Th U	Most recent data used wherever possible. Aggregate database is thought to be geographically and lithologically representative. Early (1974) data has a limited trace suite comprising F Cu Zn Rb Sr Zr Ba U.
Anorogenic Granites Of Northern Labrador [McConnell, Unpublished data]	Middle Proterozoic [ca. 1270 Ma] "anorogenic" Batholith	2,500	367	1/7 km2	F Be Li V Cr Co Ni Cu Zn Ga Rb Sr Y Zr Nb Mo Sn Ba La Ce W Pb Th U	Grid Sampling Program similar to TLGB project. Database mostly represents peralkaline granites. Associated Granitoid rocks are under-represented.

Table 9.1. Summary of databases (including TLGB data) employed in comparative geochemical studies.

Coastal Batholith Of Peru

The Mesozoic-Cenozoic Coastal Batholith of Peru
(Pitcher, 1977; Atherton, 1984; Pitcher et al., 1985) is
the type example of a "cordilleran" or "volcanic-arc"
batholith. It is situated 200 km east of the trench of an
active subduction zone, stretches for over 2000 km, and has
an average width of ca. 70 km (Figure 9.1). The following
summary is taken from the above sources.

Geological Setting : The batholith is composite, and
is divided into segments (longitudinal sectors), and
"super-units" (Cobbing et al., 1977). The latter are mafic
to felsic intrusive sequences. Diorite, quartz-diorite and
tonalite, associated with lesser mafic rocks, are their
dominant components; granitic (s.s) plutons commonly form
ring-complexes that are the youngest intrusive phases.
High, probably subvolcanic, emplacement levels were
attained by many plutons. Subaerial basalt, dacite and
rhyolite (Calipuy Group), are younger than most of the
plutonic rocks, and may not be directly related to the
exposed plutons. The dominant host rocks are Mesozoic
turbidites and mafic volcanic rocks. However, much of the
batholith is probably underlain by Phanerozoic or
Precambrian basement at depth.

Geochemical Database : Pitcher et al. (1985) list 217
XRF and INAA analyses, including volcanic rocks. These
represent "traverses" across the batholith, and are not
geographically representative of any specific area. Trace
element data are heterogeneous, due to collection by
different workers over a 20 year period. It is not clear if
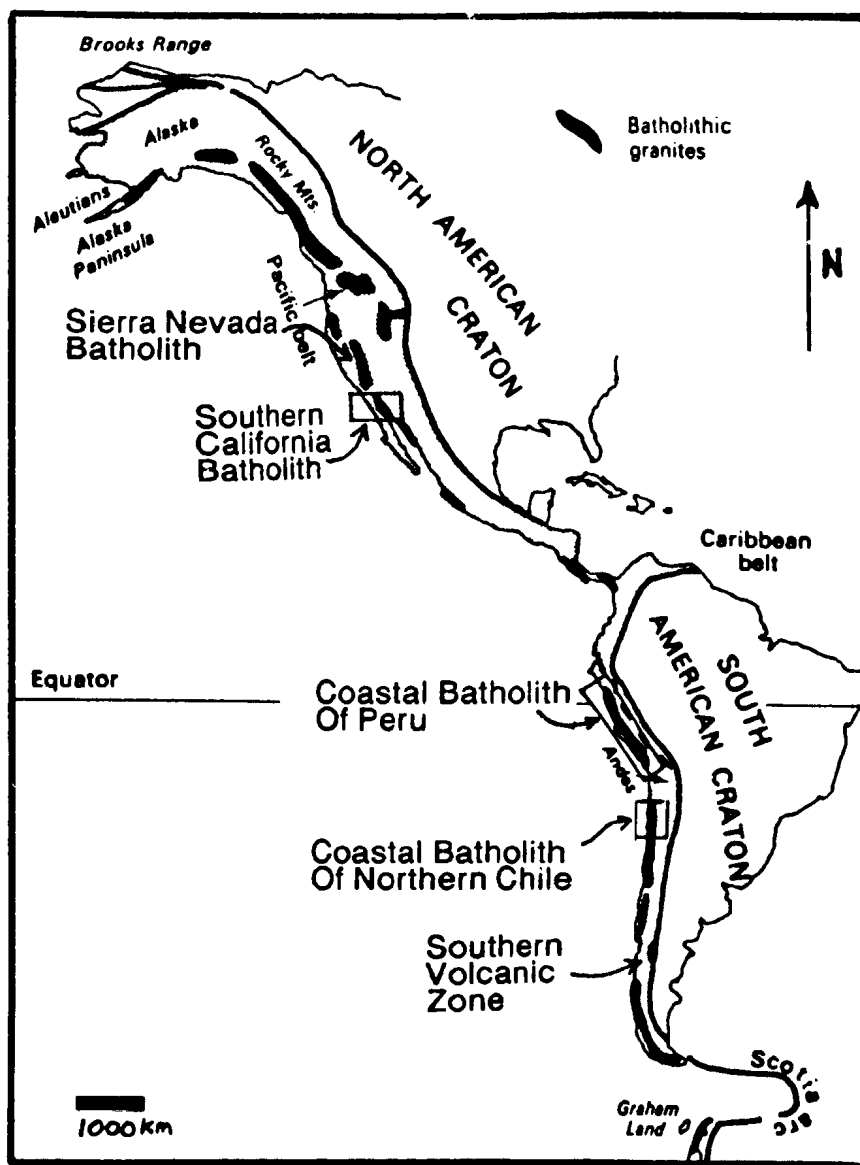they are truly representative of the Coastal Batholith.

Figure 9.1. Distribution of major volcanic-arc batholiths
in the Andean - Cordilleran orogenic belt, showing areas
discussed in this study. Adapted from Read and Watson (1975).

Mesozoic Batholith Of North-Central Chile

The coastal cordillera of northern Chile (Figure 9.1) are formed by a Mesozoic batholith that is continous with the Peruvian example and has a similar setting (Coira et al.,1982; Naranjo et al., 1986; Brown, 1987; 1988). The following summary is taken from the above sources.

Geological Setting : Plutonic rocks in this area are Triassic to Jurassic (220-160 Ma) and Cretaceous (130-100 Ma) in age. The locus of magmatism migrated eastward from the trench axis with time. Country rocks include Paleozoic metasediments containing leucogranite intrusions, overlain by Mesozoic basinal sedimentary rocks. The Paleozoic rocks are unrelated to Andean orogenesis. Most of the batholith is considered to be underlain at depth by basement of at least Paleozoic age. It is dominated by diorite, tonalite and granodiorite, with subordinate gabbro and granite (Brown, 1987; 1988). Volcanic cover rocks are not widespread, but Cenozoic volcanic rocks are widespread inland, reflecting continued eastward migration of the active volcanic front.

Geochemical Database : M.Brown (pers.comm., 1988) provided 280 unpublished analyses from this batholith. Sample collection was not rigidly structured, but the data are geographically and lithologically representative, and are far more homogeneous than those of Pitcher et al. (1985). Major and trace elements were analyzed by XRF at the British Geological Survey, and appear reliable, at least in terms of their detection limits.

Mesozoic Batholith Of Southern California

This is also a classic area of "cordilleran" magmatism, and has been intensely studied (Baird et al., 1974; DePaolo, 1981b; Baird and Miesch, 1984; Silver and Chappell, 1988). This area includes part of the Peninsular Ranges Batholith (Silver and Chappell, 1988), and also the Transverse Ranges, where the batholith is transitional to the Sierra Nevada Batholith (Figures 9.1 and 9.2). The following description is taken from the above sources.

Geological Setting : The batholith is largely of Cretaceous (140-80 Ma) age. The oldest rocks are in the west, suggesting that magmatism migrated away from the trench, as in Chile. The area in Figure 9.2 has well-developed transverse petrographic, geochemical and isotopic trends, suggesting progressively more evolved compositions to the east. Major shifts in composition coincide with faults of the San Andreas system, and it is possible that transverse trends may have been telescoped (see Baird and Miesch, 1984, for a review of discussion).

The country rocks are mostly Mesozoic metasediments in the Peninsular Ranges, but include possible Proterozoic basement material east of the San Andreas fault and in adjacent Mexico.

Geochemical Database : Baird and Miesch (1984) list 482 major element analyses from a grid-based, representative sample population analogous to the TLGB database, but with a lower sample density. Data are subdivided by geographic block (Figure 9.2). Gabbroic rocks (mostly in the west) were excluded by Baird and Miesch (1984) as they were considered to have a separate origins from the granitoid rocks. Data were acquired by XRF.
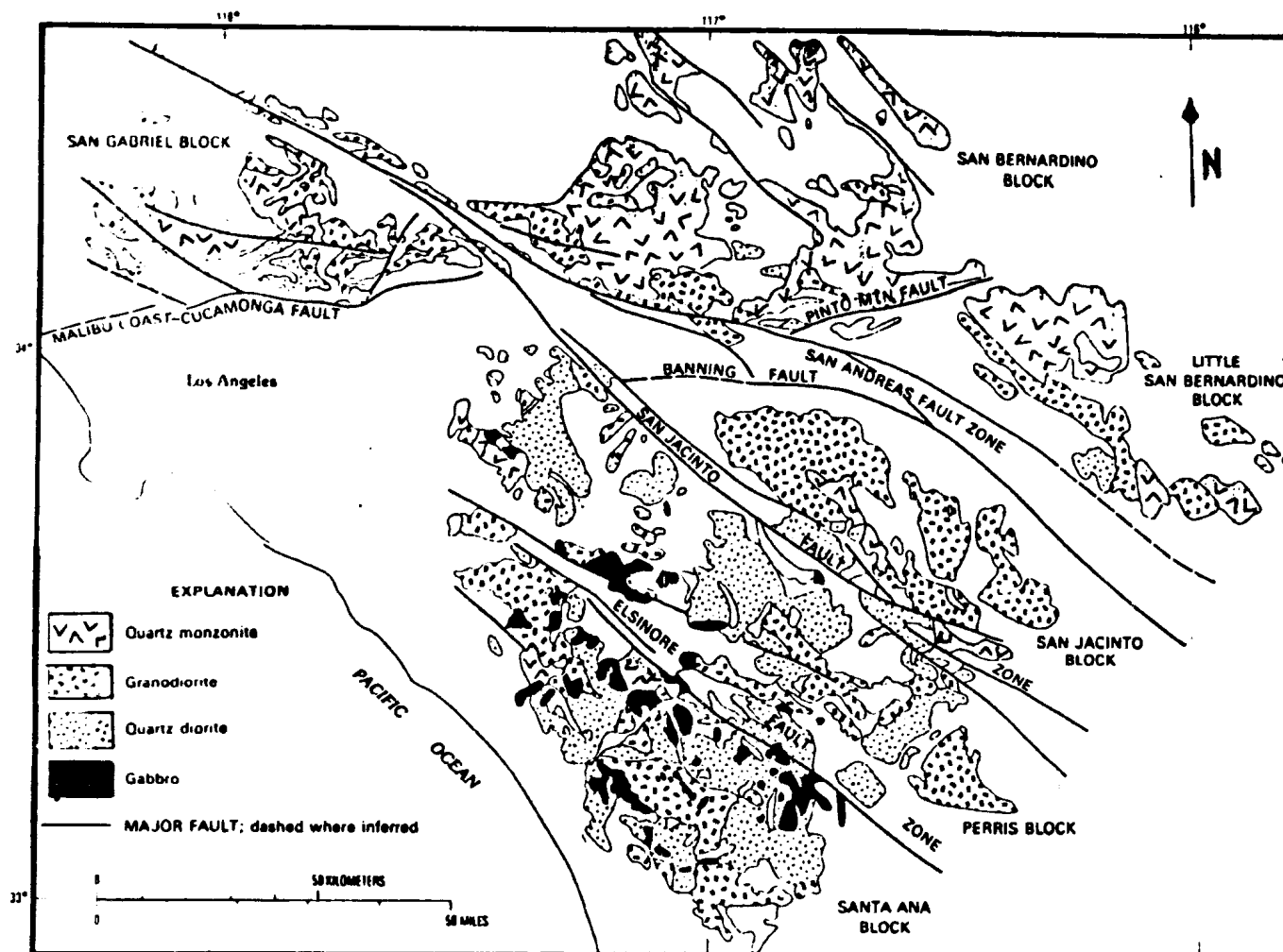
Figure 9.2. Simplified geology of the Southern California Batholith, including part of the northern Peninsular Ranges Batholith. From Baird and Miesch (1984).

Plutonic Belts of Afghanistan

The Alpine-Himalayan Belt is the type area for collisional orogenesis. The following account is summarized from studies by the CNRS of France (Debon et al.,1986; 1987a,b,c) in Afghanistan, Pakistan, Nepal and Tibet. Geochemical data from Afghanistan (Debon et al.,1987b) were utilized.

Geological Setting : Major plutonic belts in Afghanistan (Figure 9.3) comprise a tectonic collage of pre-, syn- and post-collisional magmatic provinces that belong to both Eurasian and Gondwanaland portions of the Himalayas. The oldest granitoid rocks are Lower Paleozoic (ca. 500 Ma) leucogranites, associated with earlier (unrelated) Gondwanaland events. These were followed by Triassic (210-160 Ma) and Cretaceous (100-70 Ma) polyphase granitoid batholiths that are considered to record subduction of Tethys under the Eurasian and Gondwanaland margins respectively. All of these rocks were formed prior to collision between India and Eurasia ca. 54 Ma ago.

Syn- and post-collisional magmatism occurred in Cenozoic (Eocene to Miocene) times. Rocks of this age comprise two-mica peraluminous (S-type) leucogranites of classical "Himalayan" affinity (e.g. Lanord and LeFort, 1988), and also metaluminous (I-type) granitoid rocks. Both associations transgress the tectonic boundaries between older plutonic belts, and they appear to be partly coeval. The dominant country rocks are poorly-known Mesozoic metasediments, but metavolcanic sequences, and Paleozoic (possibly also Proterozoic) metamorphic rocks occur locally.

ALPINE-HIMALAYAN BELT OF AFGHANISTAN
PLUTONIC BELTS AND DOMINANT AGE OF INTRUSIVES
(Excluding Paleozoic Intrusions)

Feroz Koh -- Cenozoic
Band-e-Bayan -- Cenozoic
Northwest Farah Rod -- Cenozoic
Spin Boldak -- Cenozoic
Western Nuristan -- Cenozoic

Eastern Nuristan -- Cretaceous-Cenozoic
Helmand -- Cretaceous
Arghandab -- Cretaceous
Safed Khers -- Cretaceous (?)
Wakhan -- Cretaceous

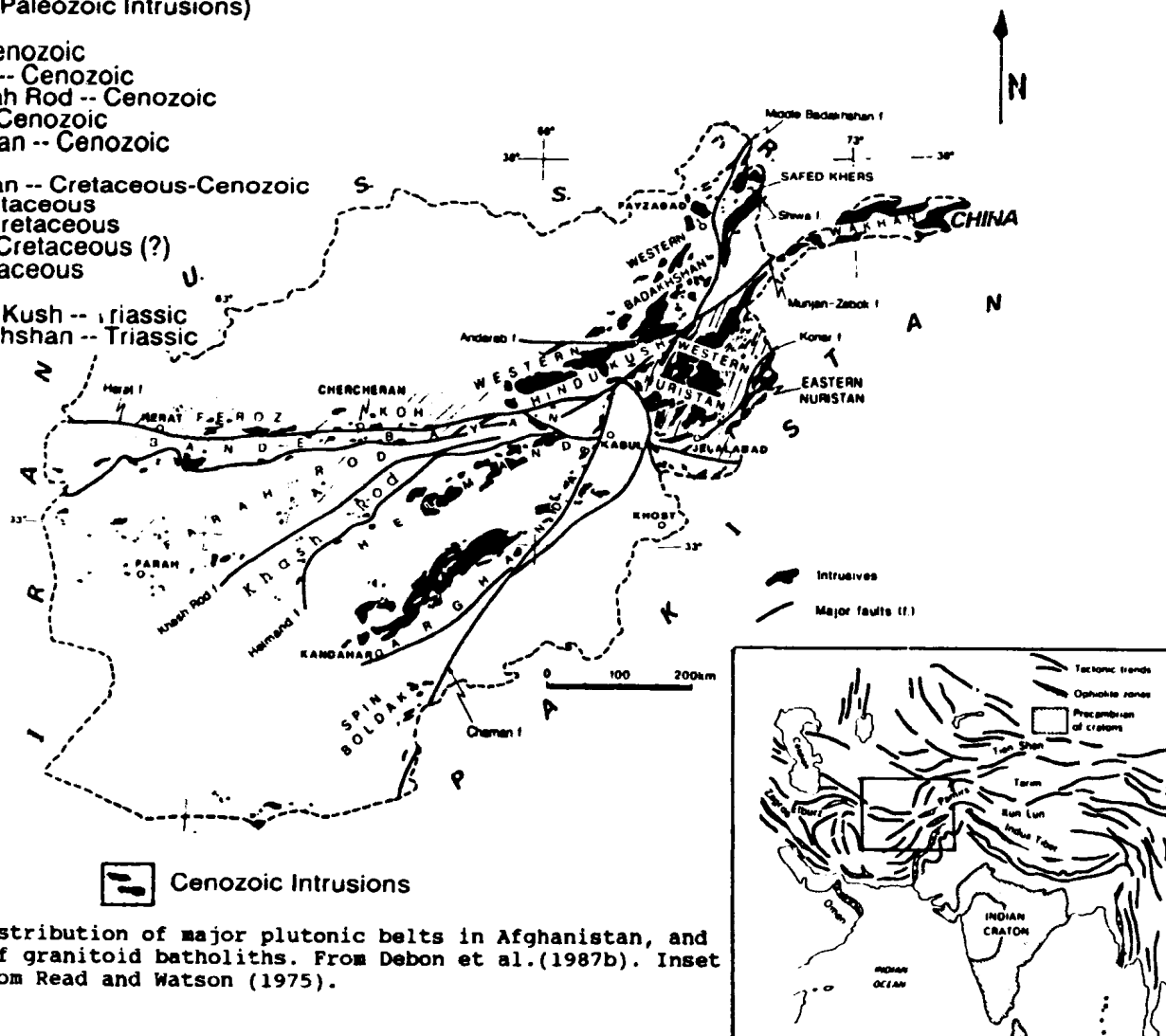Western Hindu Kush -- Triassic
Western Badakhshan -- Triassic

Intrusives

Major faults (f.)

Cenozoic Intrusions

Figure 9.3. Distribution of major plutonic belts in Afghanistan, and
location of granitoid batholiths. From Debon et al.(1987b). Inset
adapted from Read and Watson (1975).

Geochemical Database : F.Debon (pers.comm., 1988) provided 723 analyses from the ARTEMISE data bank. The data are subdivided according to age and plutonic belt; this study is concerned with 334 Cenozoic granitoid rocks and 336 samples from Mesozoic batholiths; analyses from Paleozoic granites were excluded. Mesozoic batholiths are of interest mostly in terms of their correspondence to assemblages that retain a spatial relationship to subduction (e.g. Peru, Chile). The area covered by the Afghan data is immense, and sample locations were governed largely by access; however, Debon et al.(1987b) consider the database to be representative on a broad scale. All data are XRF; the trace element suite is very limited, and useful data are present only for V, Rb, Ba and Sr.

Late- and Post-Orogenic Granitoid Rocks Of Newfoundland

Appalachian-Caledonian granites define an important subtype in the classification of Pitcher (1983). The Newfoundland Appalachians are a two-stage collisional orogen that have been compared directly to the Alpine-Himalayan belt (Colman-Sadd, 1982). Voluminous granitoid rocks in the central portion of the orogen (Figure 9.4) mostly post-date closure of Iapetus (locally) during the Taconic Orogeny. Although it is simplistic to burden these suites with a single label such as "collisional", they provide a good representation of the character of magmatism in later stages of Phanerozoic orogenic cycles. The following summary is drawn largely from Hayes et al.(1987), Dickson et al.(1988), and Williams et al.(1989).
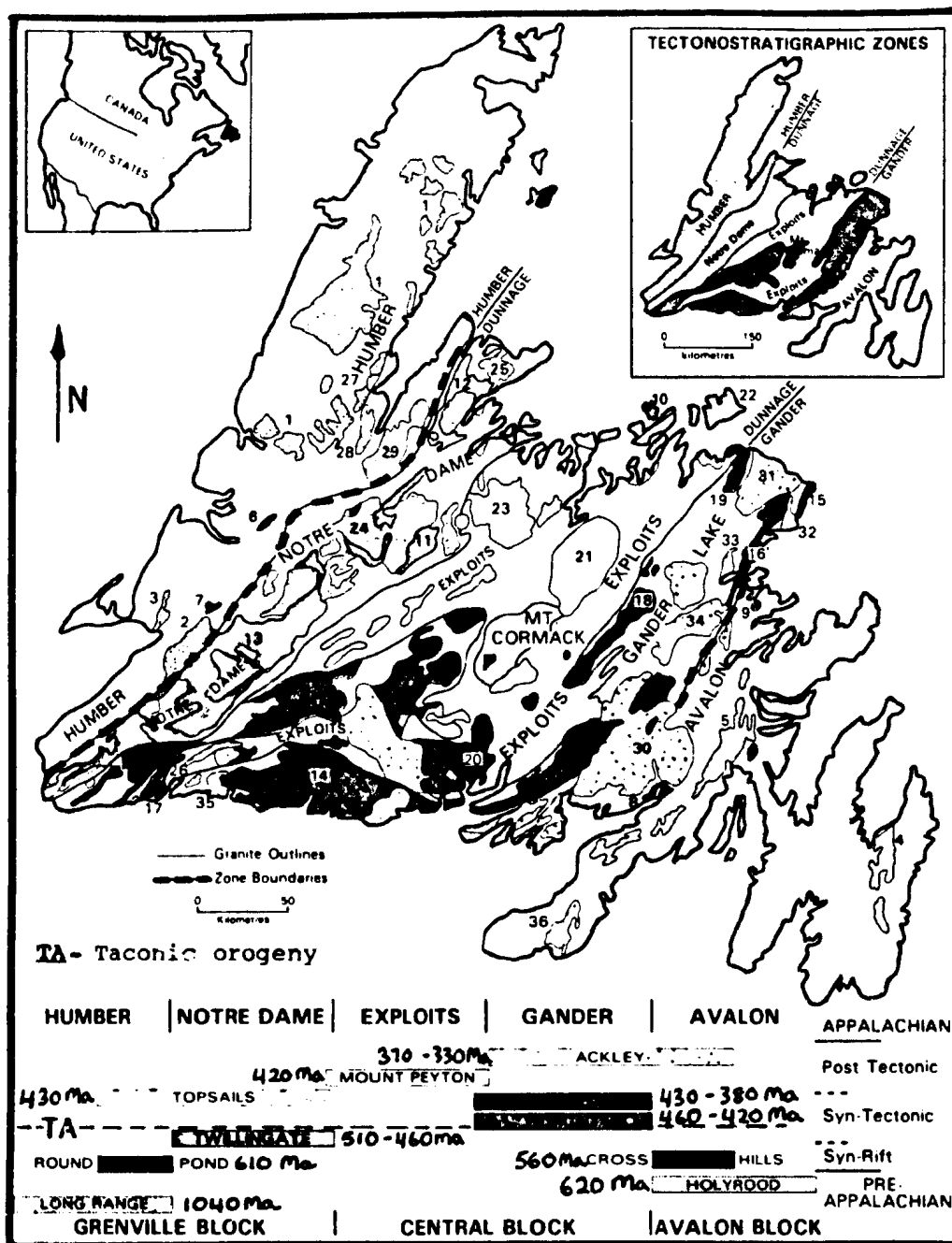
Figure 9.4. Distribution and setting of granitoid intrusive rocks in the Newfoundland Appalachians. From Williams et al.(1989).

Geological Setting : Granitoid rocks in Newfoundland
are divisible into several groups, which are assigned names
from type localities (Figure 9.4). Ordovician suites are
considered to represent volcanic-arc environments that
predate the Taconic orogeny. Post-Taconic, (largely
Siluro-Devonian) magmatism continued for up to 100 Ma, and
transcends the Devonian Acadian orogeny. The country rocks
vary from ocean-floor and island-arc volcanic assemblages
in the Dunnage Zone to high-grade metamorphic rocks in the
Gander Zone and Precambrian volcanosedimentary sequences in
the Avalon Zone.

Variably foliated, metaluminous to peraluminous
("S-type") granites (Burgeo and Middle Ridge type) in the
metasedimentary Gander Zone are considered to have been
generated during accretionary or collisional events
(Williams et al., 1989). Undeformed Siluro-Devonian
(predominantly I-type) plutons of the Topsails, Ackley and
Mount Peyton associations (Figure 9.4) transgress the major
zones of the orogen, and are probably post-collisional.
Some (e.g. Topsails) are peralkaline; a number of others
are described as "A-type" granites (Hayes et al., 1987). No
attempt is made here to subdivide these diverse rocks
according to age or zone; they are treated as a single
assemblage. There appear to be systematic differences in
geochemistry and isotopic character between the various
tectonic zones (Dickson et al., 1988; B.Fryer, pers.comm.,
1988), that probably record the influence of contrasting
lower crustal blocks.

Geochemical Database : Geochemical studies include
early work (Strong et al., 1974), and several recent
investigations (e.g. Dickson, 1983; Dickson et al.,1989).
Since 1982, grid-based sampling programs akin to the TLGB
study have been employed. Data for the Topsails Igneous
Suite were provided by Whalen et al. (1987b).

There are great variations in sample density amongst
these studies. An optimum sampling density (ca. 1 sample
per 25 km^2) was therefore established, and intensely
sampled plutons were reduced to this level by random
selection of a sample subset. It is felt that the aggregate
database of 1202 analyses is approximately representative.
Individual plutons are not equally represented, but
associations defined by Williams et al.(1989) are included
in rough proportion to their areal extent.

Wherever possible, the most recent data have been
employed; analytical methods and precision for these are
equivalent to this study (Appendix A). Other sources are
primarily XRF data, and of reasonable to good quality
(Strong et al., 1974; Whalen et al., 1987b).

Proterozoic Anorogenic Granites Of Northern Labrador

Anorogenic, within-plate suites of Phanerozoic age
(e.g. Kinnaird and Bowden, 1987) are very poorly
represented by public-domain geochemical data.

However, published and unpublished data are available
from the ca. 1270 Ma old Flowers River Igneous Suite
(Figure 9.5) in northern Labrador (Hill, 1982; Collerson,
1982; Hill and Thomas, 1983). This is similar to classic
anorogenic granitoid complexes such as the younger granites
of Nigeria, and has an anorogenic setting (Collerson, 1982;
Hill, 1982).

Geological Setting : The complex is part of a major
belt of Middle Proterozoic plutons extending from Labrador
to the midcontinent United States (Emslie, 1978; Anderson,
1983). The Flowers River Suite is spatially associated with
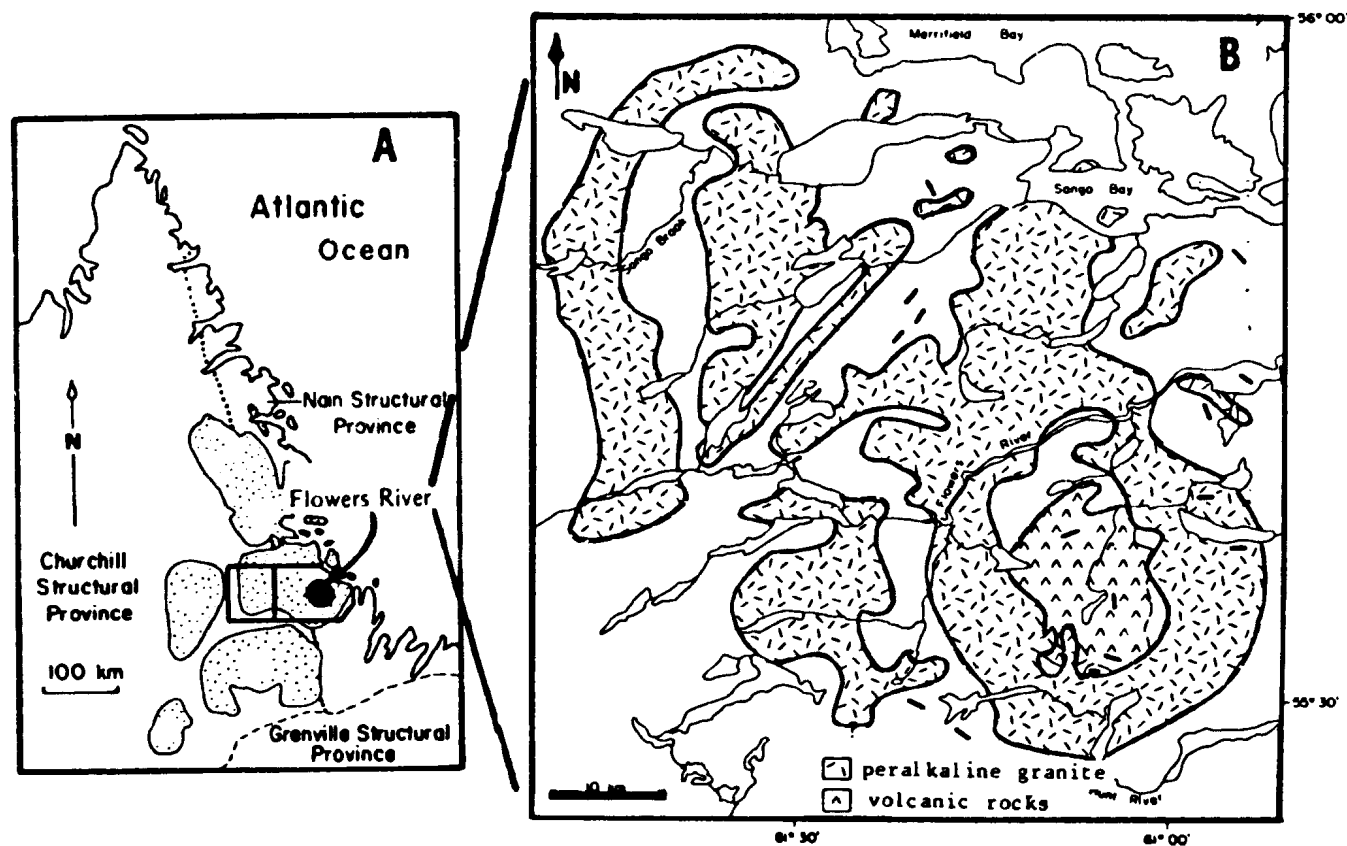granitoid rocks of the Nain Igneous Complex, and is similar

Figure 9.5. Location and distribution of peralkaline, anorogenic granitoid rocks of the Flowers River Igneous Suite in Northern Labrador. Stippled areas in (A) are the anorthosite-granitoid plutons (e.g. Nain Igneous Complex) with which these rocks are spatially associated. From Hill (1982).

in age to some of them (Collerson, 1982). It is dominated
by subsolvus and hypersolvus metaluminous to peralkaline
granites and associated volcanic rocks. The Nain Igneous
Complex includes anorthosite, monzonite, fayalite-bearing
syenite and granite. Anorthositic rocks are probably not
directly related to the granites, but are an integral part
of most Proterozoic anorogenic complexes (Emslie, 1978).
The country rocks are high-grade Archean and Proterozoic
gneisses of the Nain and Churchill Provinces. The
peralkaline granites were emplaced as high-level ring
complexes (Hill, 1982; 1988). The granitoid rocks of the
Nain Complex probably form sheath-like units around and
above the anorthosites (B.Ryan, pers.comm., 1988)

Geochemical Data : McConnell (1986) sampled the
complex using a 2 x 2 km random grid system, and provided
367 unpublished analyses. Most represent peralkaline and
associated metaluminous granites, but there is a
subordinate population from the Nain Complex. These are
augmented by data from Collerson (1982) and Hill (1982)
representing granitoid rocks of the Nain Complex, and a few
anorthosites. The database is representative of the area
around the Flowers River Suite but, compared to other
within-plate associations, is probably somewhat biased
towards peralkaline compositions. Trace element analysis
suites and data quality are equivalent to TLGB and
Newfoundland databases.

A-type Granites of The Lachlan Fold Belt

The Paleozoic Lachlan Fold Belt of southeastern
Australia was used by Collins et al.(1982) to define the
characteristics of "A-type" granites. 45 analyses from

these rocks (Whalen et al.,1987b) are used here. These are post-orogenic, metaluminous, variably hypersolvus granites (s.s.) that have enhanced levels of LFS and HFS trace elements (Collins et al., 1982). The database is too small for analysis of compositional spectra, but it has been used to assess differentiation trends for "A-type" granites relative to the other assemblages. This is required because there is some disagreement about the diagnostic features of so-called "A-type" suites (e.g. Tuach et al., 1986; Whalen et al., 1987) versus highly fractionated granites assigned to I- or S-type associations.

9.2 COMPARATIVE MAJOR ELEMENT GEOCHEMISTRY

9.2.1 Comparative Frequency Spectra

To facilitate comparisons between assemblages, all
histograms for each variable are scaled equally, using 20
frequency intervals (Figure 9.6). This procedure requires
exclusion of small amounts (<1%) of outlying data. Vertical
(percentage frequency) scales may differ between
assemblages.

Major Element Frequency Spectra

SiO$_2$ (Figure 9.6a) : Magmatic arc assemblages (e.g.
Peru, Chile) have broad, approximately normal, frequency
distributions with maxima at 57 to 65 % SiO$_2$; those from
California and Afghanistan (Figure 9.7) are displaced to
slightly higher SiO$_2$. All arc assemblages have expanded
SiO$_2$ frequency distributions. In contrast, Newfoundland
and Afghanistan (Cenozoic), and Flowers River, have
asymmetric, negatively-skewed distributions with maxima at
71-77% SiO$_2$.

Both TLGB assemblages have bimodal SiO$_2$ histograms;
in Labradorian rocks, the lesser peak is at gabbro-diorite
composition, compared to monzonite-syenite in the
Makkovikian rocks. In general terms, Makkovikian rocks
resemble collisional or within-plate assemblages, and are
totally distinct from volcanic arc assemblages.

MgO (Figure 9.6b) : MgO frequency spectra are
superficially similar for all assemblages. However,
collisional and within-plate assemblages are strongly
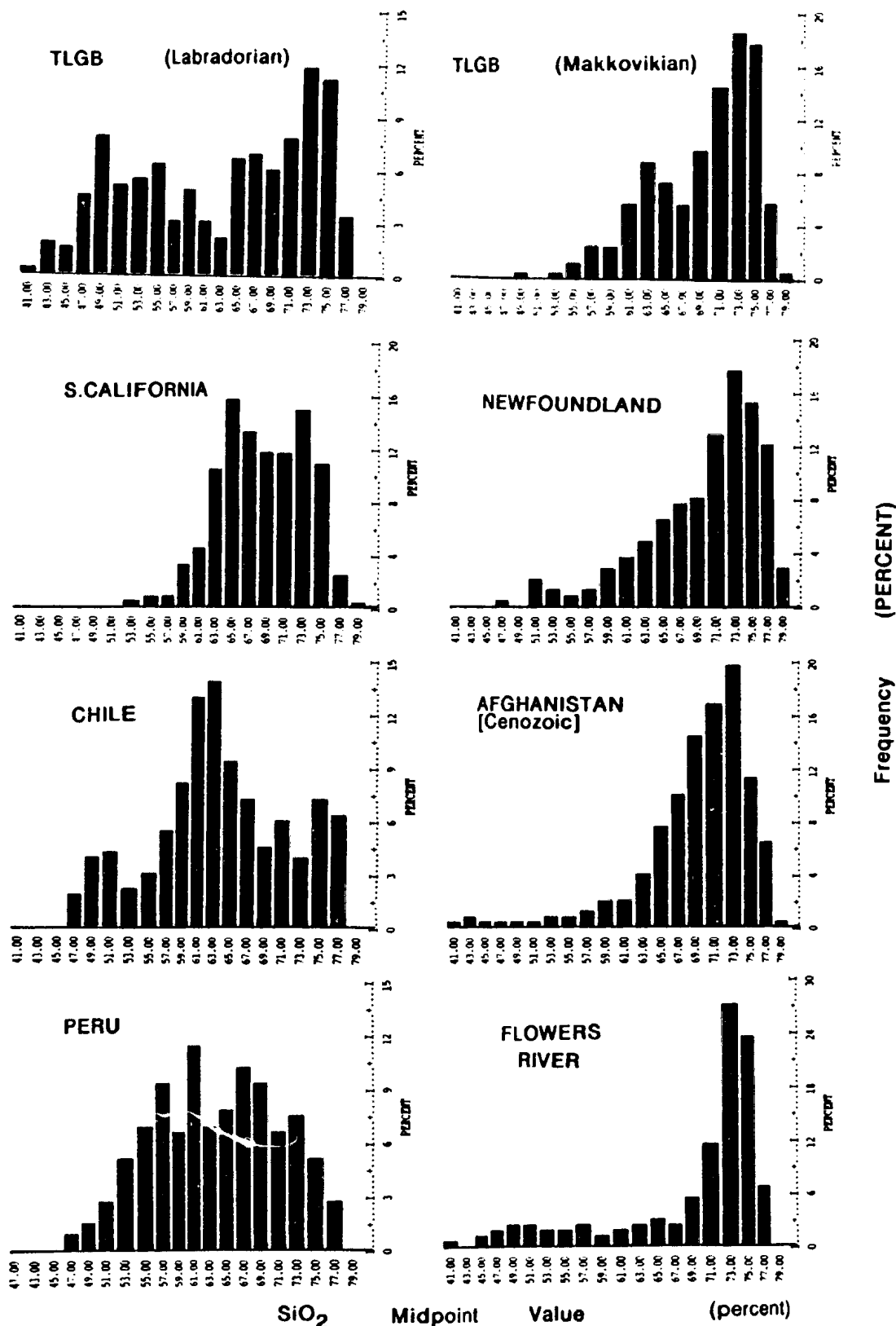depleted in MgO relative to volcanic arcs. Makkovikian

Figure 9.6a. Comparative SiO₂ frequency spectra.

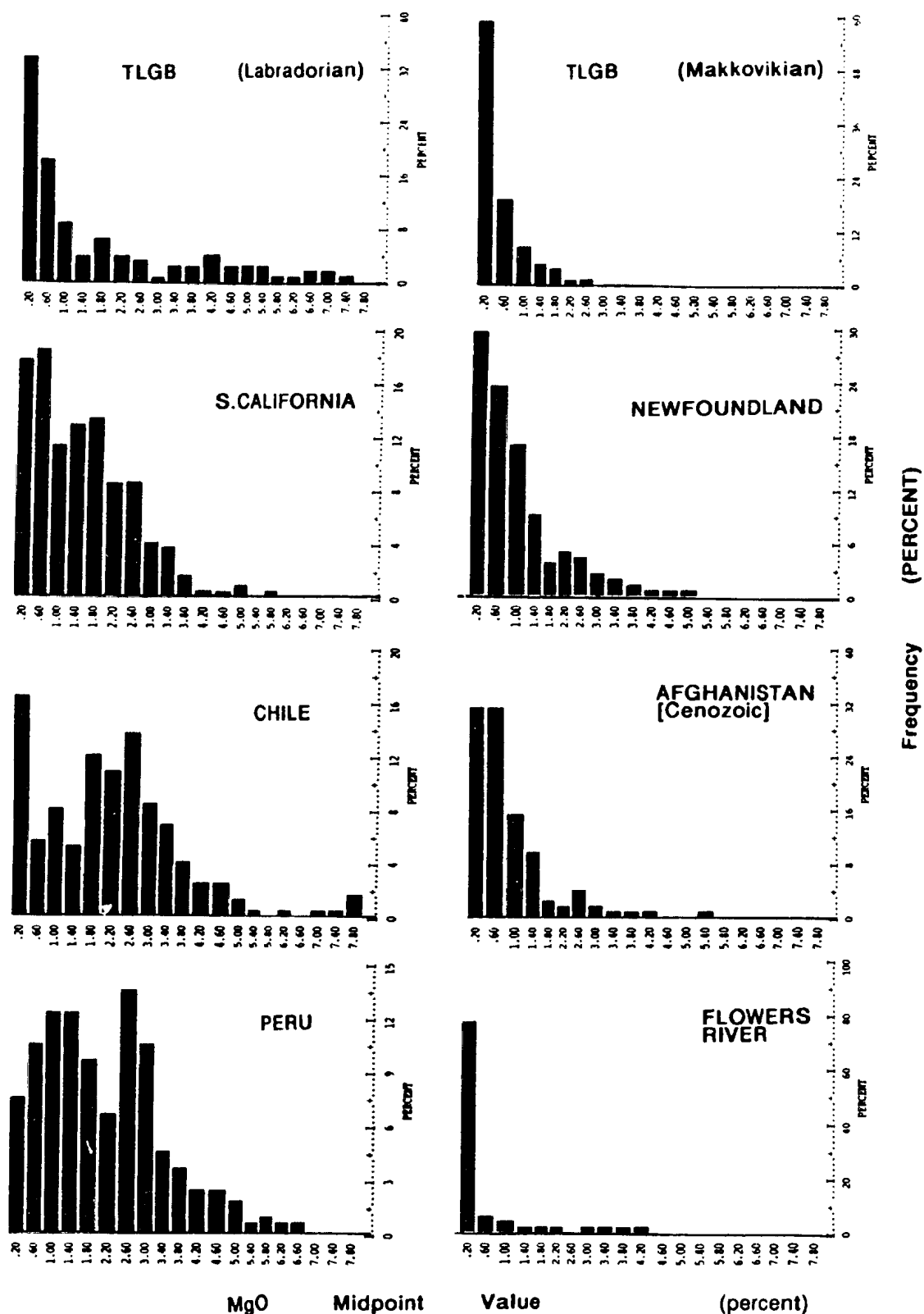Figure 9.6b. Comparative MgO frequency spectra.

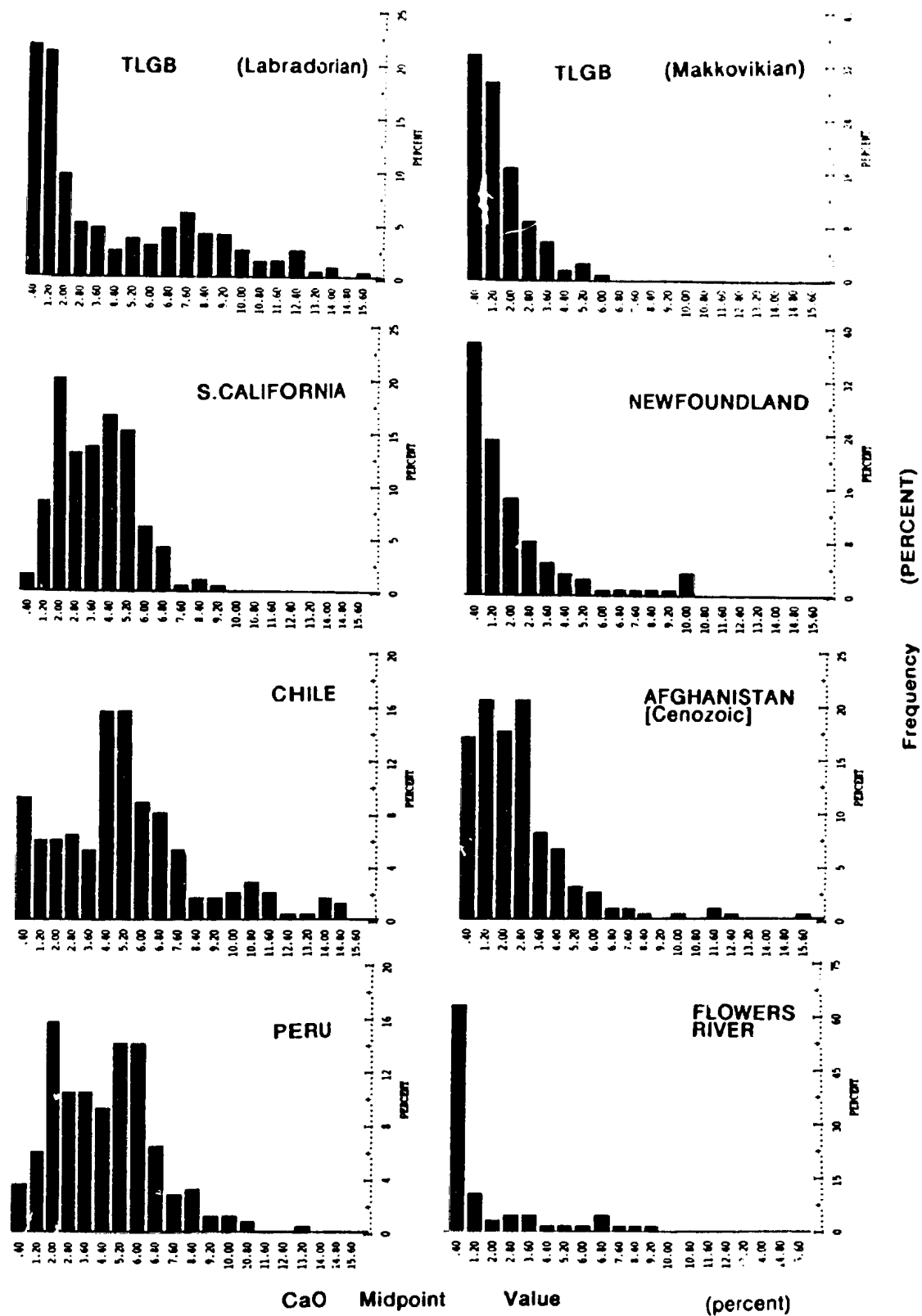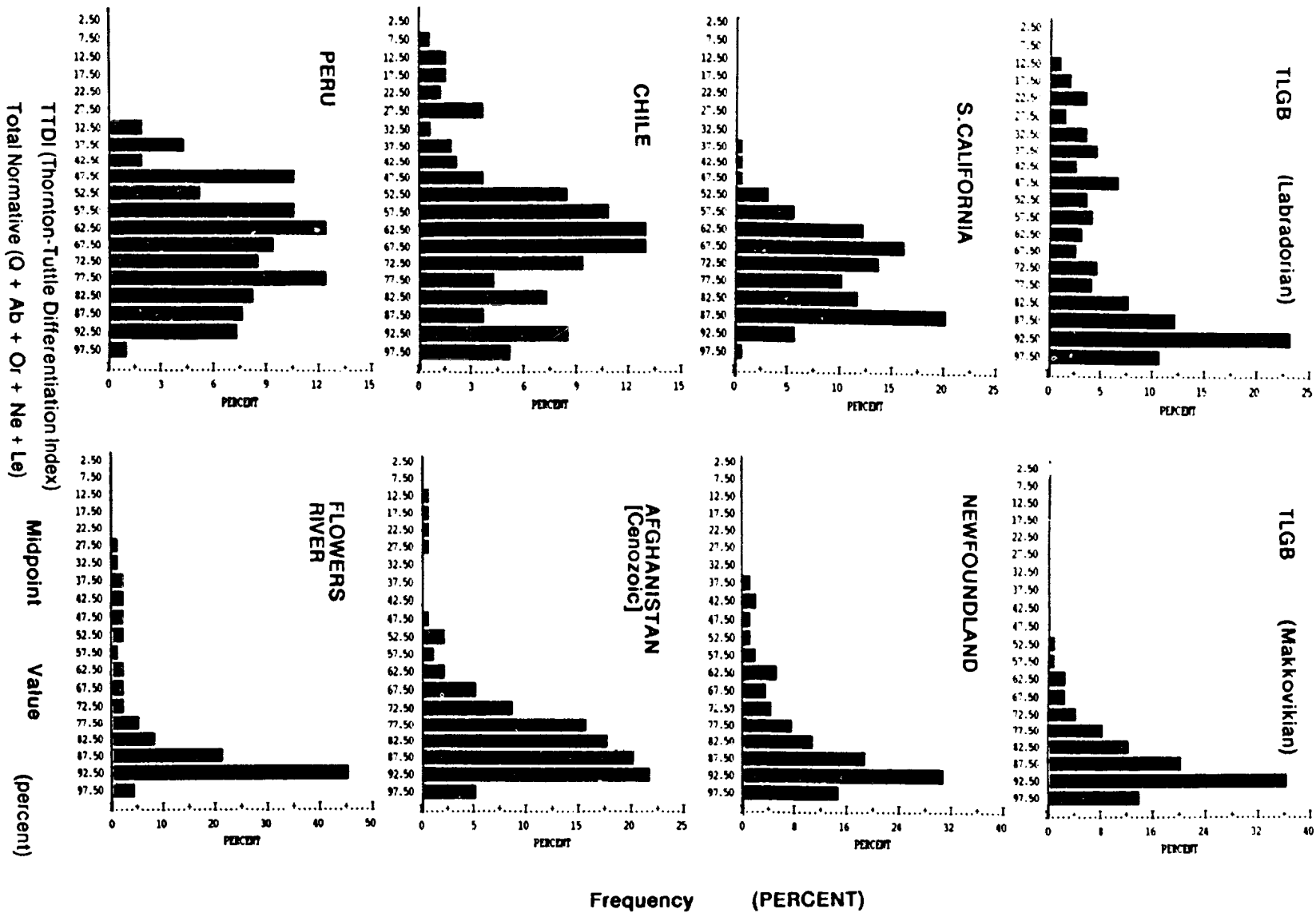Figure 9.6c. Comparative CaO frequency spectra.

PERU

CHILE

S.CALIFORNIA

TLGB (Labradorian)

FLOWERS RIVER

AFGHANISTAN [Cenozoic]

NEWFOUNDLAND

TLGB (Makkovikian)

PERCENT

Frequency (PERCENT)

Figure 9.6d. Comparative Differentiation Index (TTDI) frequency spectra.

TTDI (Thornton-Tuttle Differentiation Index)

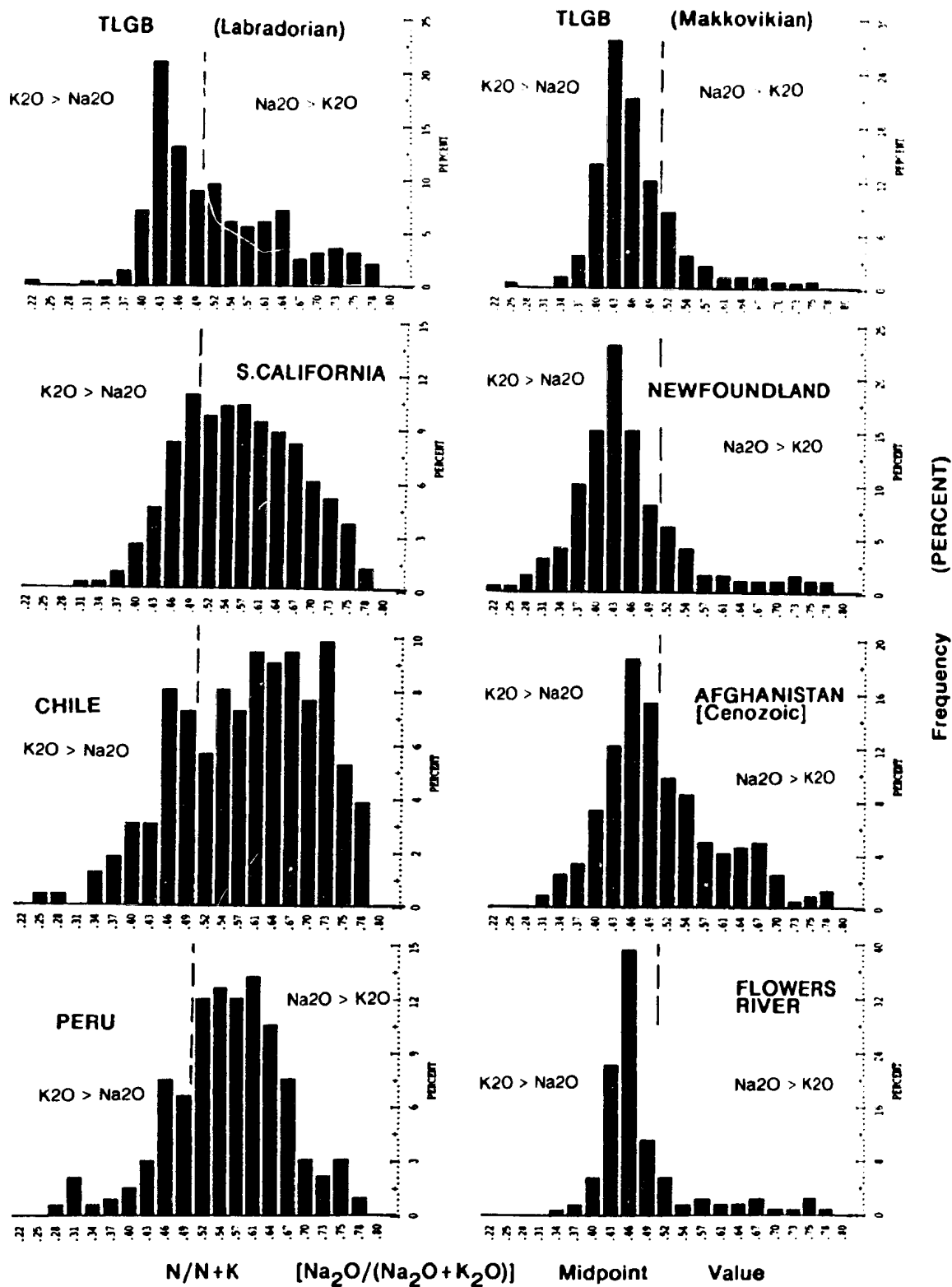Total Normative (Q + Ab + Or + Ne + Le)

Midpoint   Value   (percent)
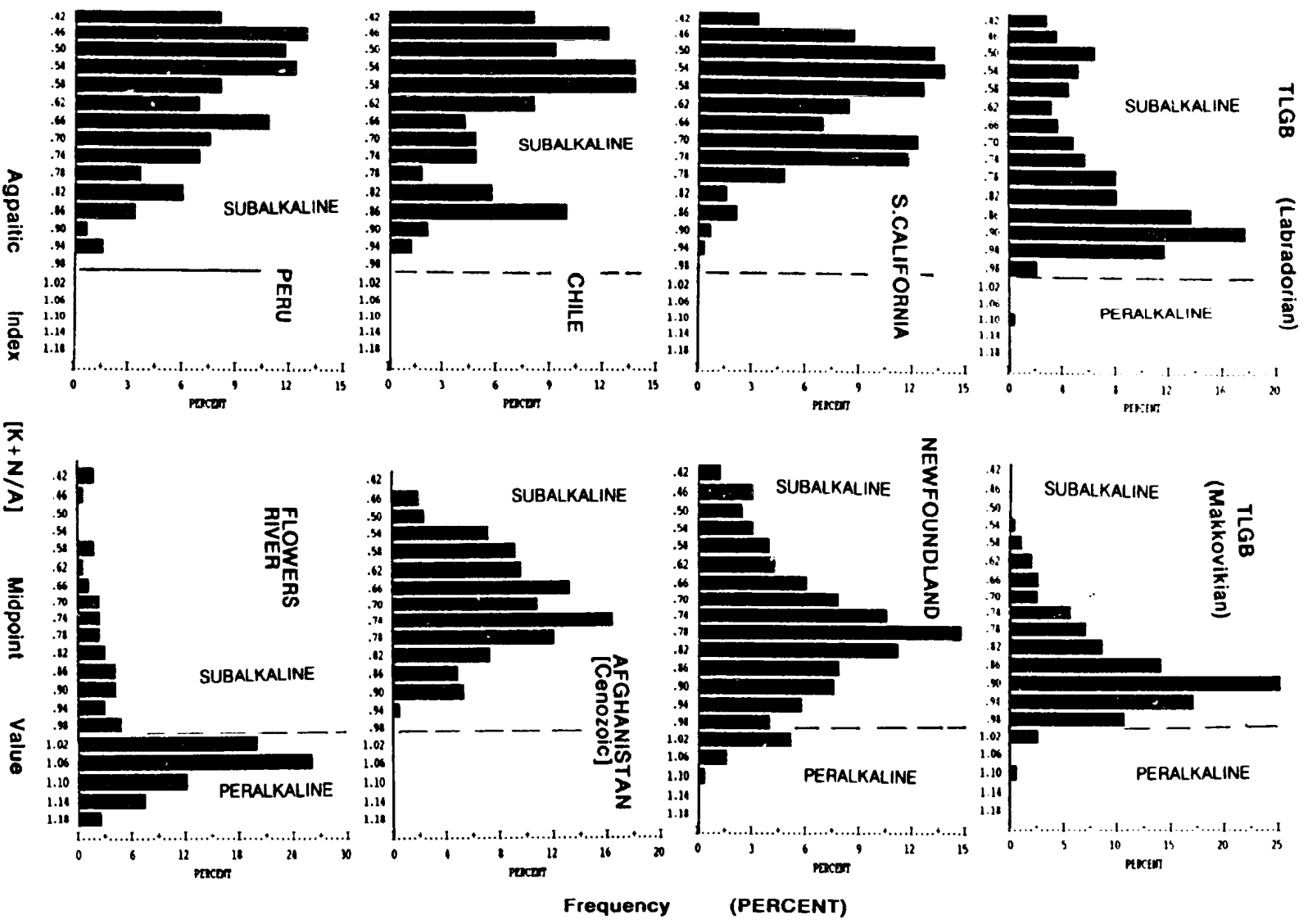
Figure 9.6e. Comparative N/N+K frequency spectra.

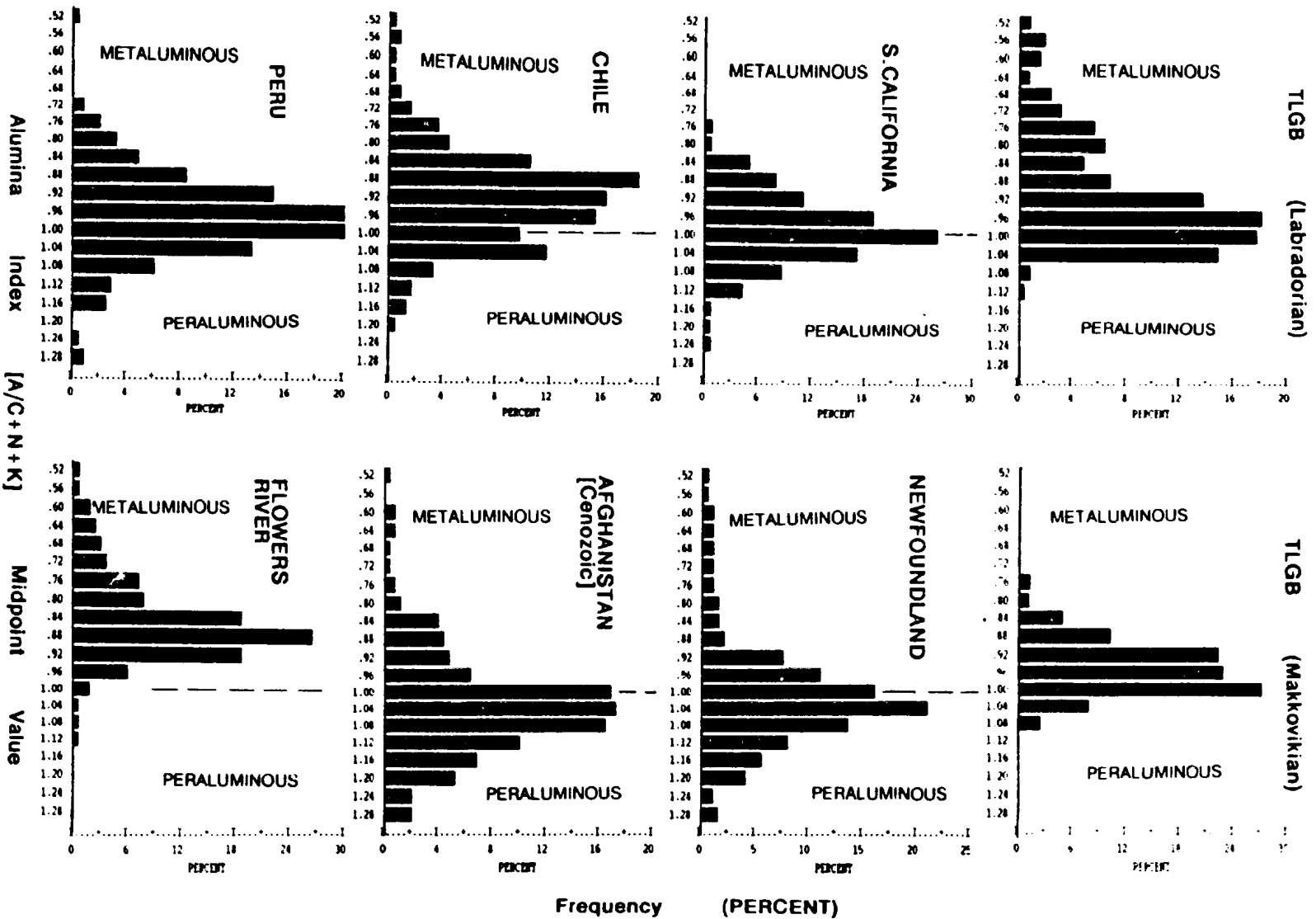Figure 9.6f. Comparative Agpaitic Index frequency spectra.
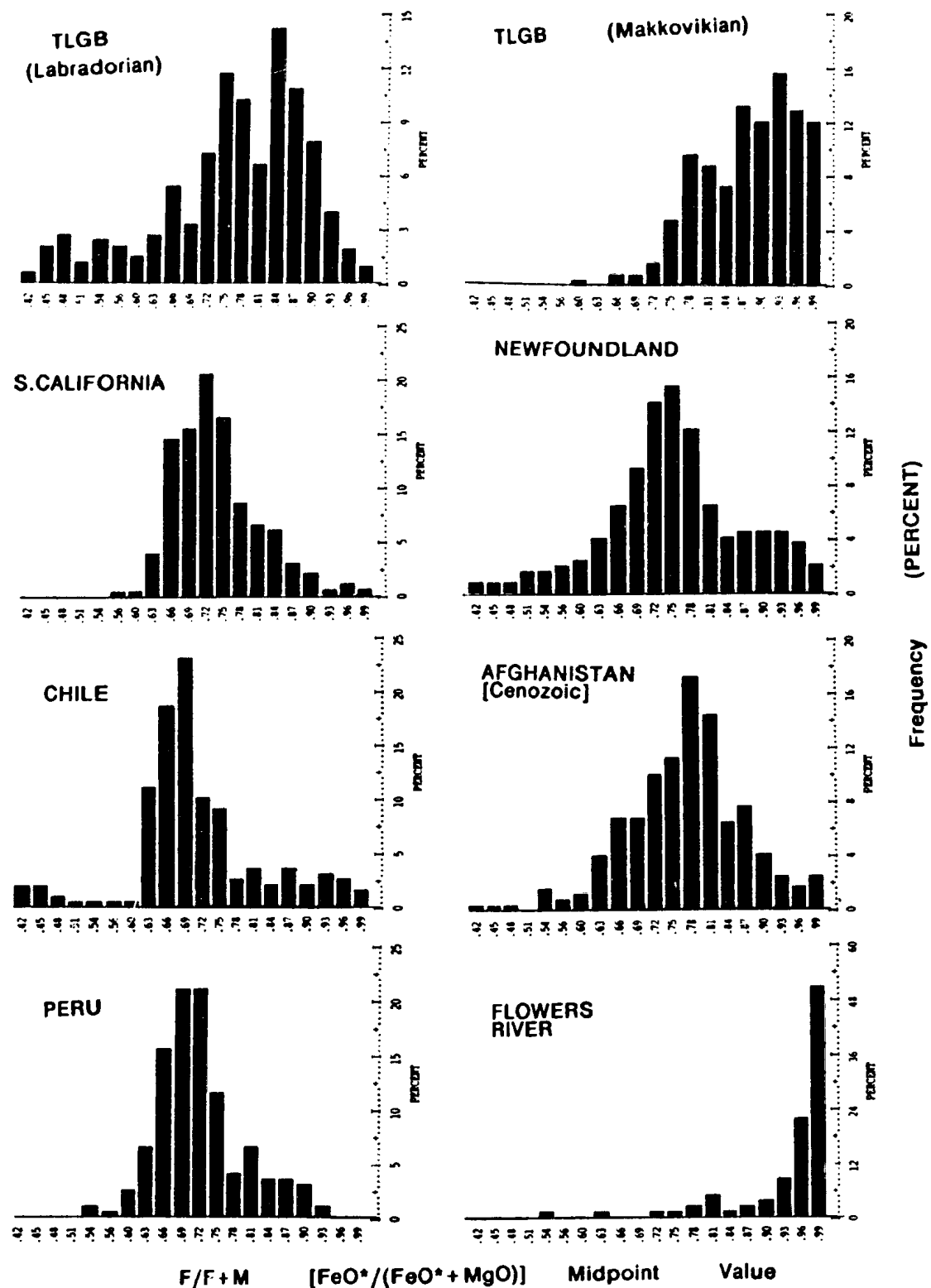
Figure 9.6g. Comparative Alumina Index Frequency spectra.

Figure 9.6h. Comparative F/F+M frequency spectra.

suites resemble both collisional and within-plate
assemblages, but more closely resemble the latter.
Labradorian suites show a wide range of MgO (mostly
reflecting the mafic rocks of the Adlavik and Mount
Benedict Suites), but are also dominated by MgO-poor
compositions compared to arc assemblages.

CaO (Figure 9.6c) : CaO spectra resemble MgO
spectra, and distinguish arc and collisional assemblages in
a similar manner. The Makkovikian suites have a closer
affinity to collisional assemblages than to within-plate
assemblages. The Labradorian assemblage is distinctly
bimodal.

Major Element Ratio and Function Frequency Spectra

TTDI (Differentiation Index) (Figure 9.6d) : The
Thornton-Tuttle Differentiation Index (TTDI; sum of
normative Q + Ab + Or + feldspathoids) is superior to
SiO_2 as an indicator of igneous differentiation, as it is
less dependent upon silica-saturation.

TTDI spectra discriminate arc and collisional
assemblages in a similar manner to SiO_2. The bimodal
SiO_2 frequency distributions of TLGB assemblages are,
however, less obvious in their TTDI spectra. This contrast
reflects the presence of evolved intermediate felsic rocks
(e.g. monzonite and syenite) in both TLGB assemblages;
these have moderate SiO_2 contents, but high TTDI values.

N/N+K (Figure 9.6e) : Arc assemblages are
predominantly sodic ($Na_2O>K_2O$), and have broad, normal
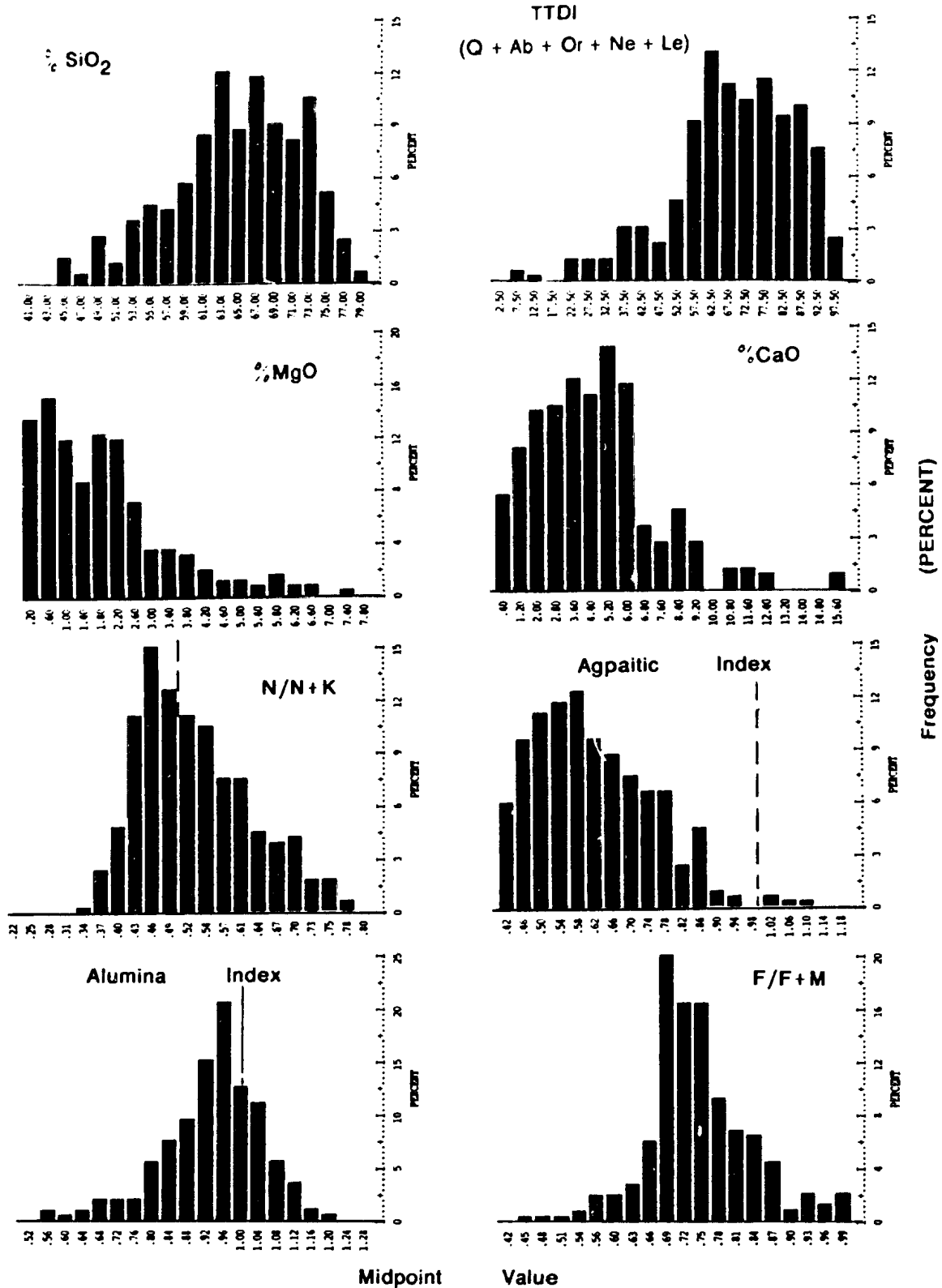to negatively skewed, frequency spectra. They contrast

Figure 9.7. Frequency spectra for major elements and derived
parameters in Mesozoic batholiths from Afghanistan. Compare with
arc assemblages (PERU, CHILE, S.CALIFORNIA) in Figure 9.6.

strongly with the narrow, positively skewed, potassic
($K_2O>Na_2O$) frequency distributions of collisional and
within-plate assemblages.

The Makkovikian assemblage is closely similar to
Newfoundland and Afghanistan (Cenozoic) assemblages, but
also resembles Flowers River. The Labradorian spectrum is
unique, but is clearly potassic relative to the arc
assemblages.

K+N/A -- Agpaitic Index (Figure 9.6f) : Arc
assemblages have positively skewed, commonly bimodal,
patterns with maxima at ca. 0.5 and ca. 0.7; they do not
include peralkaline rocks. Collisional assemblages have a
more restricted range (maxima ca. 0.8), and Newfoundland
includes ca. 7 % peralkaline compositions.

The Makkovikian assemblage is similar to the
Newfoundland assemblage, but has distinctly higher K+N/A at
0.9 to 1.0. The Labradorian assemblage is bimodal, but
includes some rocks with similarly high K+N/A values.
Neither TLGB assemblage is as extreme in composition as
Flowers River, where ca. 60% of compositions are
peralkaline.

A/C+N+K -- Alumina Index (Figure 9.6g) : All suites
except Chile and Flowers River have similar frequency
spectra with peaks at ca. 1.0. Collisional assemblages
include by far the largest proportion (> 50%) of
peraluminous rocks, whereas the Flowers River assemblage is
devoid of such material. Both Makkovikian and Labradorian
assemblages contain fewer peraluminous rocks than
collisional or arc assemblages, and rarely include rocks
with A/C+N+K > 1.1 (lower limit for S-type granites;
Chappell and White, 1974).

F/F+M (Figure 9.6h) : Arc and collisional assemblages
both have peaks at ca. 0.7 - 0.8. Granitoid rocks from
Flowers River are distinguished by very high F/F+M (>0.95).

The Makkovikian assemblage has a negatively skewed
distribution (maximum at 0.9 to 0.96) that has some
affinity to the Flowers River Spectrum, but is not as
extreme or restricted. Labradorian suites are bimodal and
compositionally expanded, but also include Fe-enriched
compositions.

9.2.2 Abundance and Distribution Of Rock Types

Contrasts in compositional spectra may also be assessed
via proportions of IUGS rock types (Figure 9.8) calculated
from normative mineralogy (after Streckeisen and LeMaitre,
1979).

Arc assemblages are dominated by normative tonalite,
granodiorite and monzogranite, with significant quartz
diorite and quartz monzodiorite. Collisional assemblages
from Newfoundland are more evolved than those of
Afghanistan, but both are dominated by monzogranite to
alkali-feldspar granite, and lack significant
quartz-diorite or tonalite. The Flowers River assemblage is
dominated by alkali-feldspar granite. TLGB assemblages are
obviously bimodal, and both contain monzonite-syenite
components that are essentially absent from all other
assemblages. In general, the Makkovikian assemblage most
closely resembles the Newfoundland assemblage. The
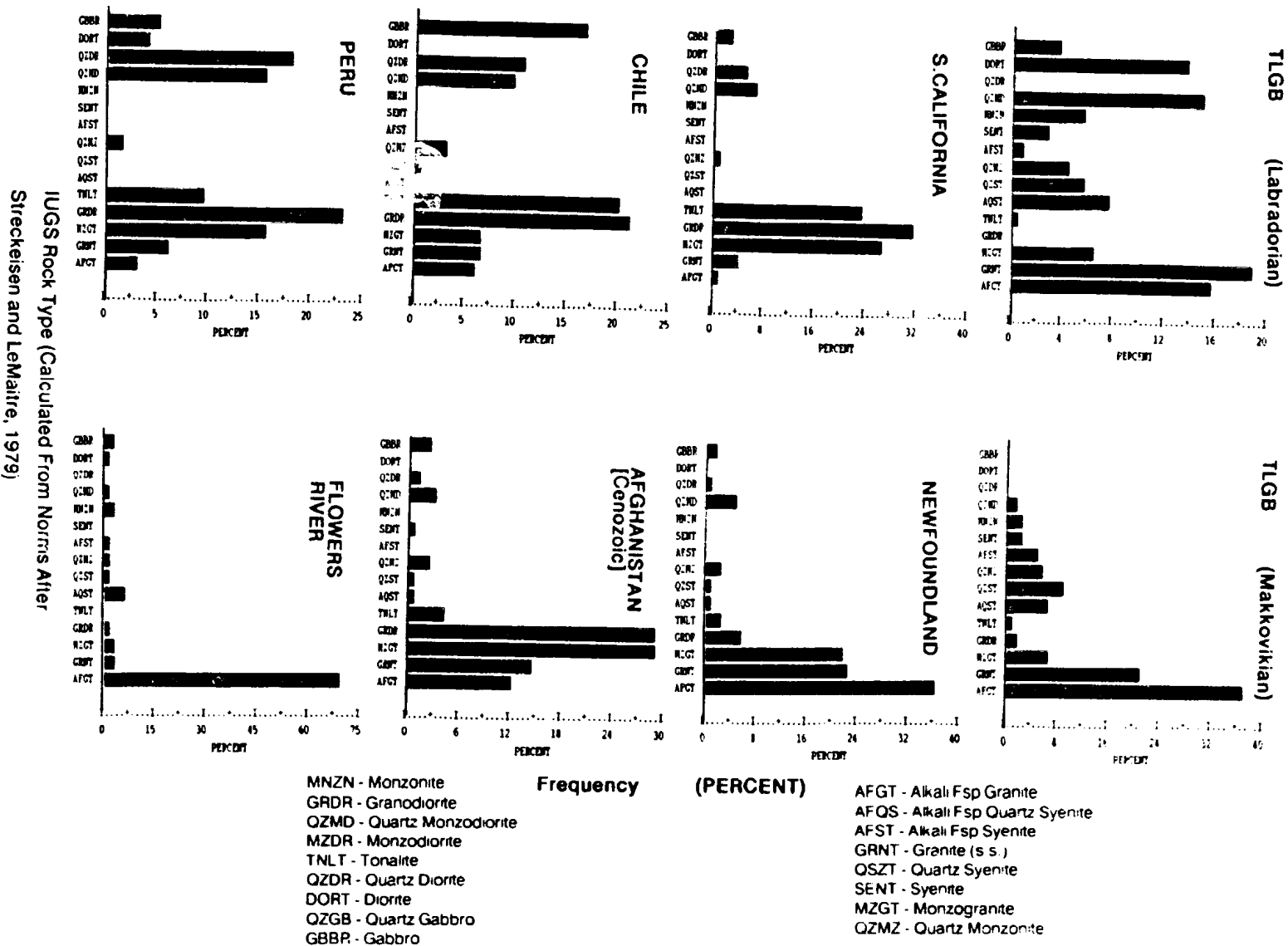Labradorian assemblage has no obvious analogue.

Figure 9.8. Proportions of IUGS rock types in the TLGB assemblages and comparative assemblages (calculated from normative data after Streckeisen and LeMaitre, 1979).

IUGS Rock Type (Calculated From Norms After Streckeisen and LeMaitre, 1979)

PERU

CHILE

S.CALIFORNIA

TLGB (Labradorian)

FLOWERS RIVER

AFGHANISTAN (Cenozoic)

NEWFOUNDLAND

TLGB (Makkovikian)

Frequency (PERCENT)

MNZN - Monzonite
GRDR - Granodiorite
QZMD - Quartz Monzodiorite
MZDR - Monzodiorite
TNLT - Tonalite
QZDR - Quartz Diorite
DORT - Diorite
QZGB - Quartz Gabbro
GBBR - Gabbro

AFGT - Alkali Fsp Granite
AFQS - Alkali Fsp Quartz Syenite
AFST - Alkali Fsp Syenite
GRNT - Granite (s s.)
QSZT - Quartz Syenite
SENT - Syenite
MZGT - Monzogranite
QZMZ - Quartz Monzonite

9.2.3 Evolutionary Trends

Quartz-Poor Versus Quartz-Rich Trends

Contrasts of compositional anatomy described above are placed in an evolutionary context in the Q'-ANOR diagram (Figure 9.9) of Streckeisen and LeMaitre (1979). Arc assemblages have quasi-linear trends extending from gabbro to granite (s.s.), but cluster primarily in the quartz and anorthite-rich tonalite and granodiorite fields. Collisional assemblages are shifted to more evolved compositions (monzogranite to granite), but lie essentially on the same "quartz-rich" evolutionary t͏ ͏ d.

Both TLGB assemblages have arcuate, "quartz-poor" trends that proceed from gabbro to alkali-feldspar granite via monzonite and syenite (Figure 9.9). The Flowers River assemblage, although restricted in compositional range, has a similar quartz-poor evolutionary trend, but is virtually anorthite-free at silicic compositions. These trends are analogous to those defined by Bowden et al.(1984) using the ternary Quartz - Plagioclase - Alkali-feldspar modal diagram, where "within-plate" assemblages such as the Nigerian younger granites have similar quartz-poor evolutionary trends.

These quartz-rich and quartz-poor trends are visible also in the Q-Ab-Or system (Figure 9.10), where the TLGB and Flowers River assemblages have well-defined trends from the Ab-Or join at Or_{40} to the ternary minumum area. These correspond to the general location of the plagioclase - alkali-feldspar cotectic at low pressures and An contents (James and Hamilton, 1969).
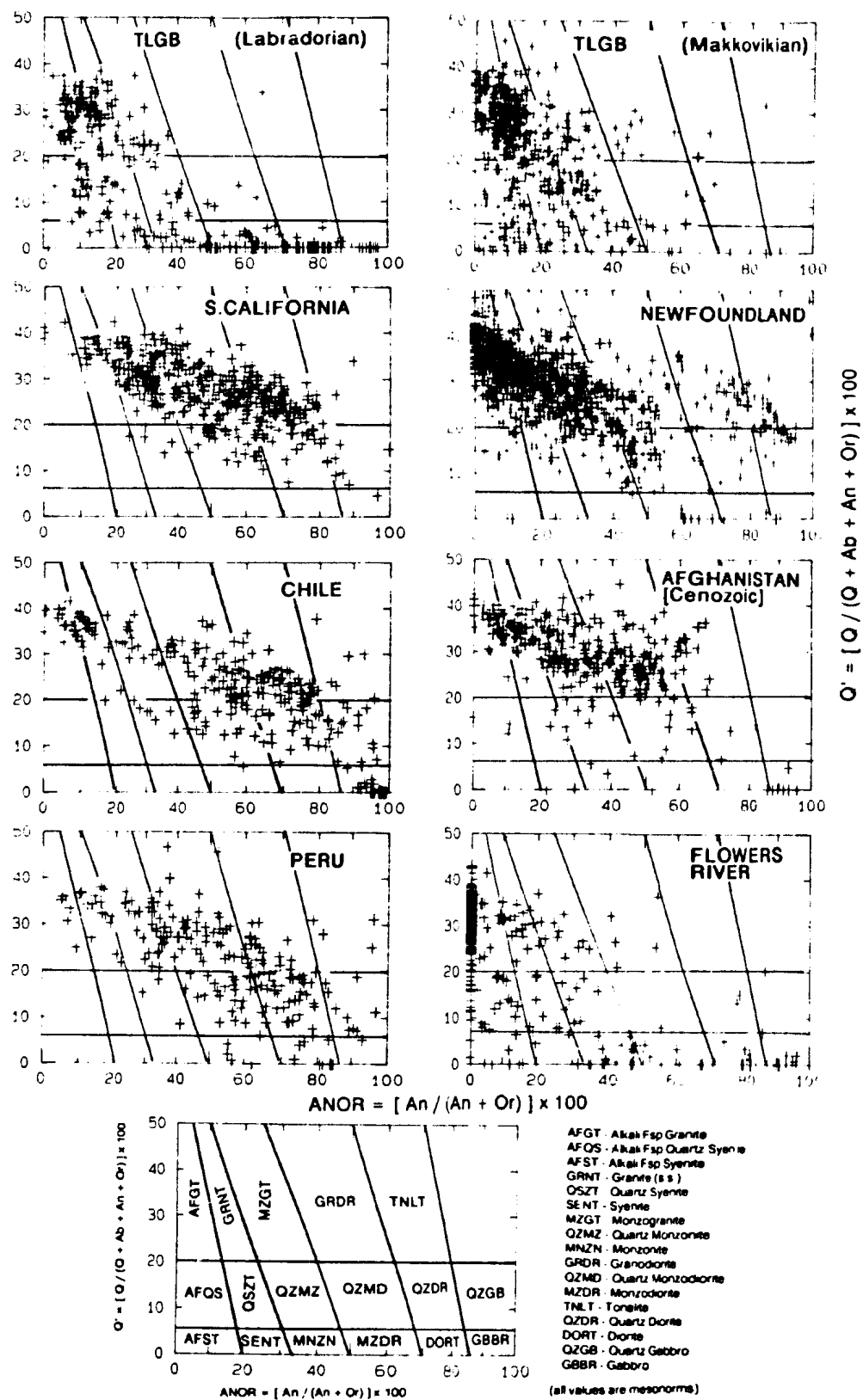
Figure 9.9. Distribution of the TLGB and comparative assemblages in the Q' - ANOR diagram of Streckeisen and LeMaitre (1979).
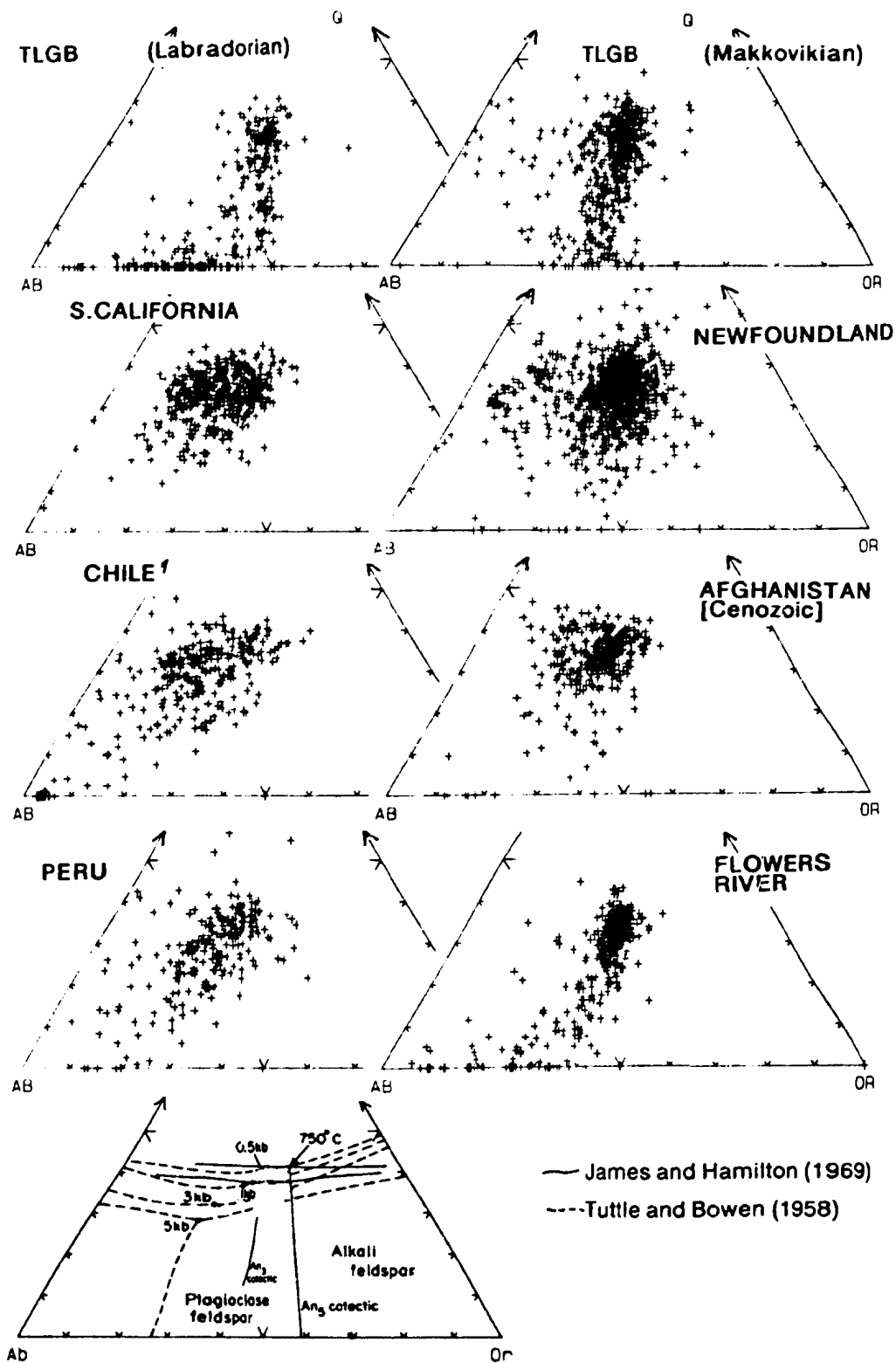
Figure 9.10. Distribution of the TLGB and comparative assemblages in the quartz - albite - orthoclase ternary system.

Major Element Differentiation Trends

Differentiation trends were summarized by aggregating data into SiO_2 intervals of 5% width, and calculating univariate statistics for each interval. Minor numbers of data (< 1%) with SiO_2 < 37.5% or SiO_2 > 82.5% were excluded in this procedure. "A-type" granites of the Lachlan Fold Belt (Collins et al.,1982; Whalen et al., 1987b) are also included in this compilation. No <u>direct</u> association via liquid line-of-descent is implied by this largely descriptive aggregation procedure.

AFM and CNK trends : These methods, despite wide application, are of little or no value in discrimination (see also Debon and Lefort, 1982; Bowden et al., 1984). Summary trends (Figure 9.11) are almost identical for all assemblages. The Flowers River assemblage lies closest to the Alkali-FeOt join, reflecting its Fe-enrichment. Petro et al. (1979) and Brown (1981) suggest this as a discrimination method for extensional or anorogenic suites, but there is no separation at the alkali-rich end of the trends.

Harker Variation Trends : Summary major element trends are closely similar for TiO_2, Al_2O_3, CaO, P_2O_5, MnO, and MgO (not figured) in all assemblages. TLGB assemblages show enrichment in K_2O and Na_2O (Figure 9.12) at all SiO_2 contents, and their high-SiO_2 trends partly coincide with Flowers River. K+N/A, A/C+N+K and F/F+M trends for TLGB assemblages lie <u>between</u> those of collisional assemblages and Flowers River, as indicated also by frequency spectra (Figure 9.6).

"A-type" granites from the Lachlan Fold belt lie closest to the Newfoundland trend, and are significantly less agpaitic than Flowers River or TLGB assemblages.
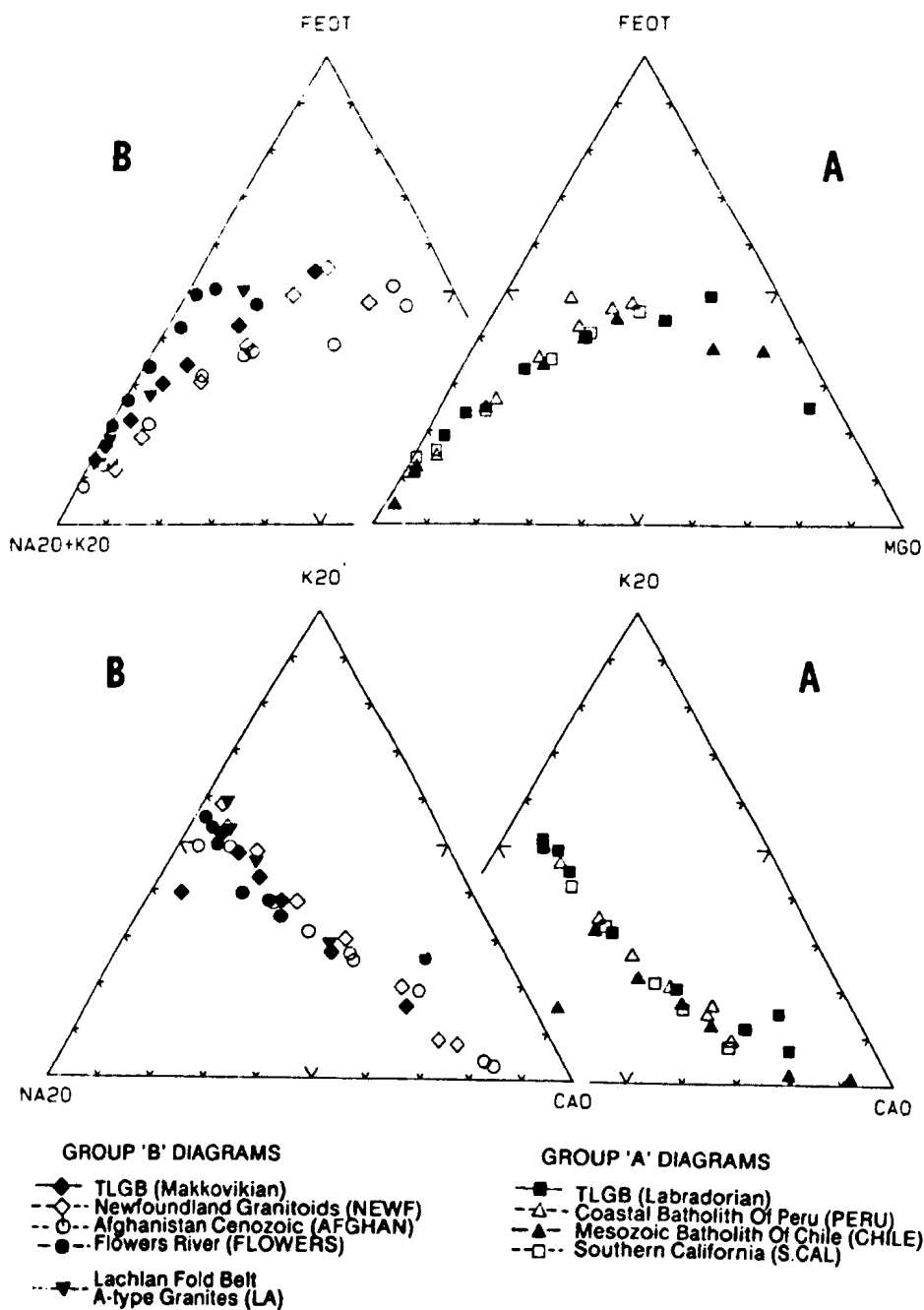
Figure 9.11. AFM and CNK trends for the TLGB and comparative assemblages. Note the lack of obvious contrasts.

A

B

Figure 9.12. Major element evolution trends for the TLGB and comparative assemblages, expressed as mean compositions for 5% SiO_2 intervals.

K_2O

Na_2O (percent)

$Fe_2O_3 T$

Agpaitic Index

$A/C+N+K$

(GROUP 'A' DIAGRAMS

% SiO_2

—■— TLGB (Labradorian)
--□-- Coastal Batholith Of Peru (PERU)
--▲-- Mesozoic Batholith Of Chile (CHILE)
--□-- Southern California (S CAL)

Midpoint Value

GROUP 'B' DIAGRAMS

—●— TLGB (Makkovikian)
--◇-- Newfoundland Granitoids (NEWF)
--C-- Afghanistan Cenozoic (AFGHAN)
—◆— Flowers River (FLOWERS)

--▼-- Lachlan Fold Belt
A-type Granites (LA)

9.3 COMPARATIVE TRACE ELEMENT GEOCHEMISTRY

Trace element data from comparative assemblages vary in completeness and quality. The Chile, Newfoundland and Flowers River databases include a trace element suite comparable to that available for the TLGB (Table 9.1), and can be compared fully. Other databases contain incomplete and/or restricted trace element suites. Mesozoic batholiths from Afghanistan are regarded here as an arc assemblage, based on their major element spectra (9.3.1; Figure 9.7) and other arguments presented by Debon et al. (1987a,b)

9.3.1 Comparative Frequency Spectra

Trace element frequency spectra were standardized in the same manner as for major elements. The number of valid cases indicated for each element (Figure 9.13) provides an indication of the completeness of data in each assemblage.

Trace Element Spectra

Vanadium (Figure 9.13a) : Vanadium spectra are broad and flat in arc assemblages, whereas collisional assemblages have log-normal, positively skewed distributions similar to MgO. There is a clear affinity between Makkovikian and collisional assemblages; the Labradorian assemblage has a wide V range similar to some arc suites, but contains a higher proportion of low-V compositions.

Rubidium (Figure 9.13b) : Rb spectra show only subtle variation. Collisional and within-plate assemblages have higher median Rb contents than arcs, and tend towards
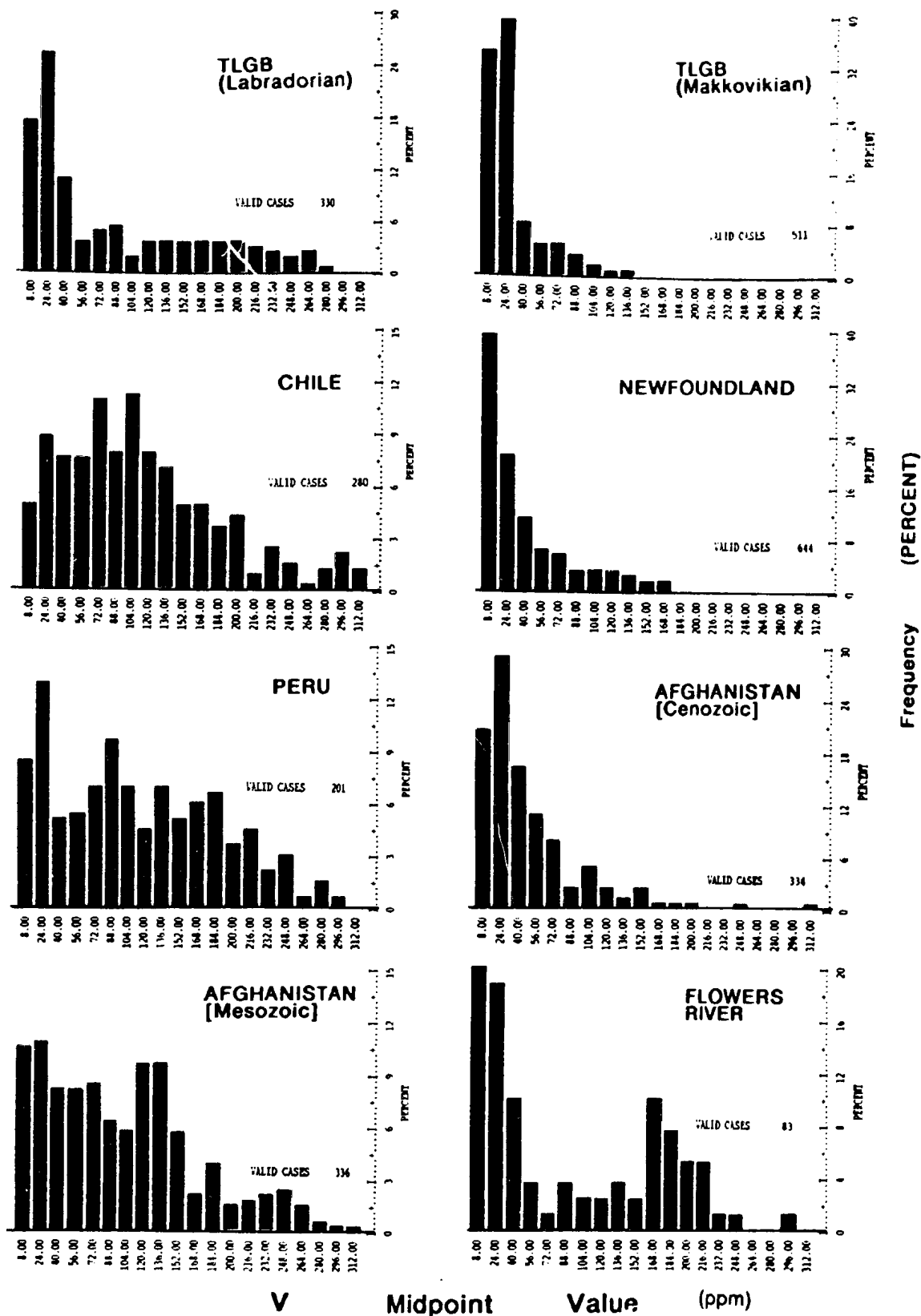
Figure 9.13a. Comparative vanadium (V) frequency spectra.

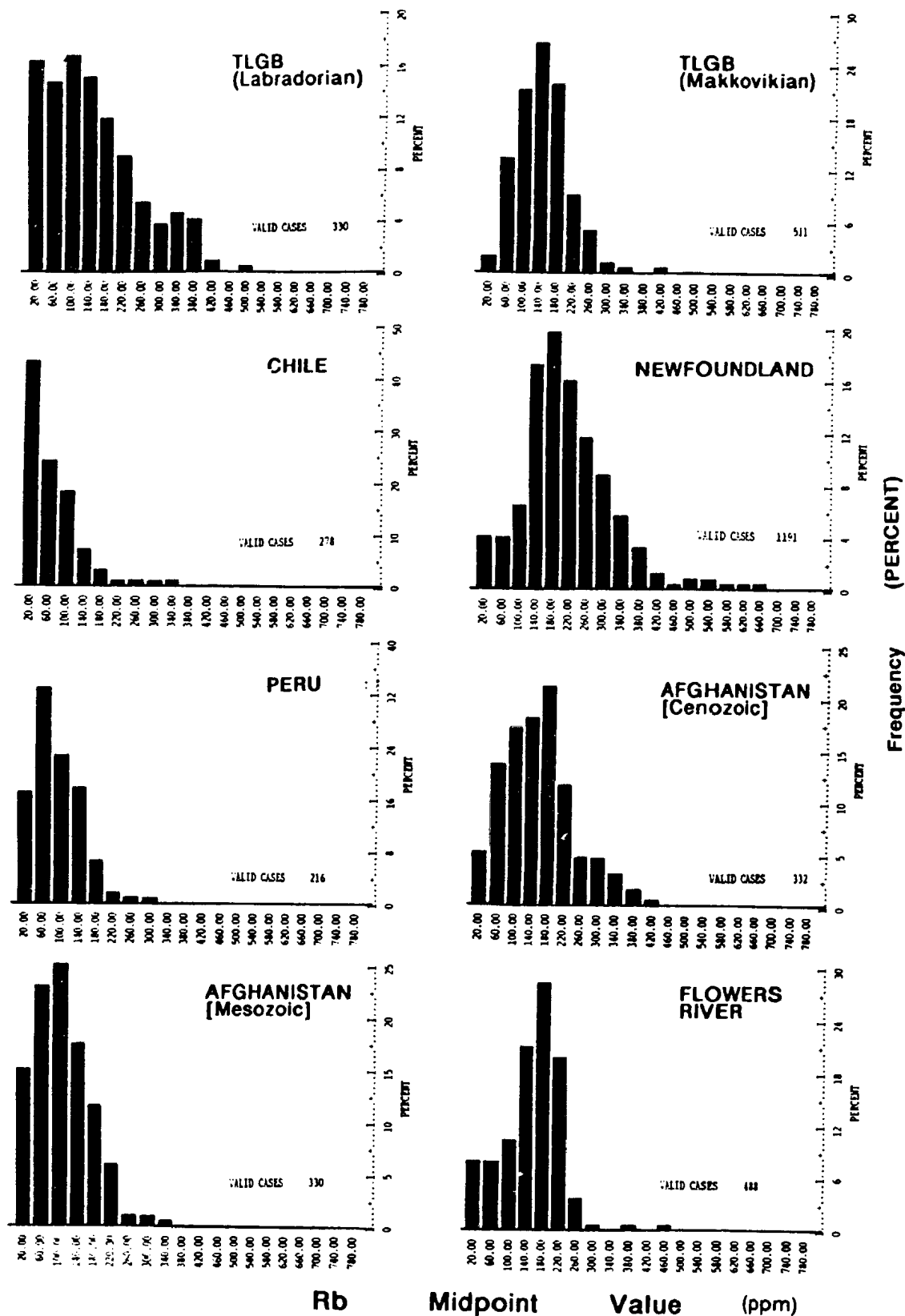Figure 9.13b. Comparative rubidium (Rb) frequency spectra.

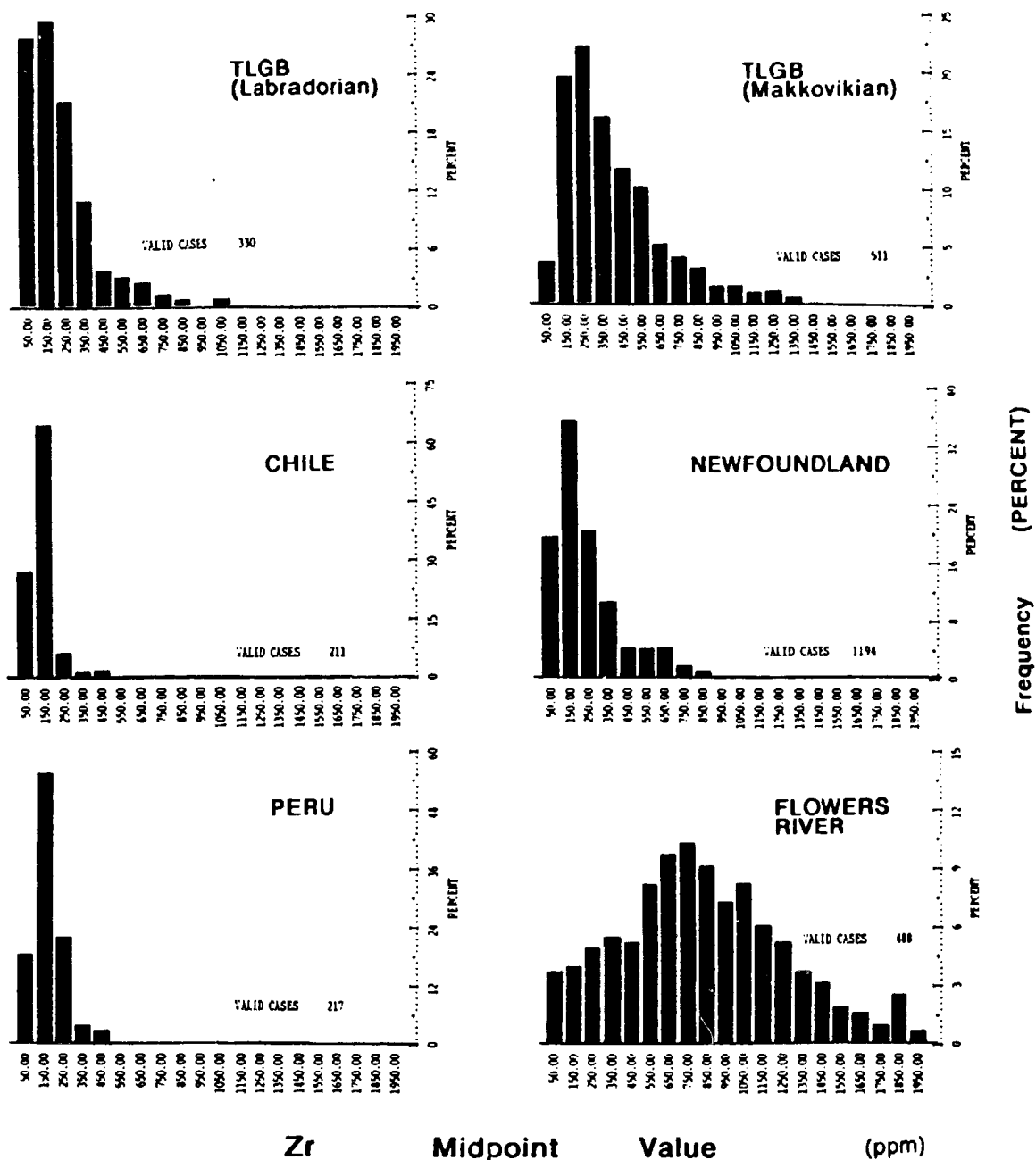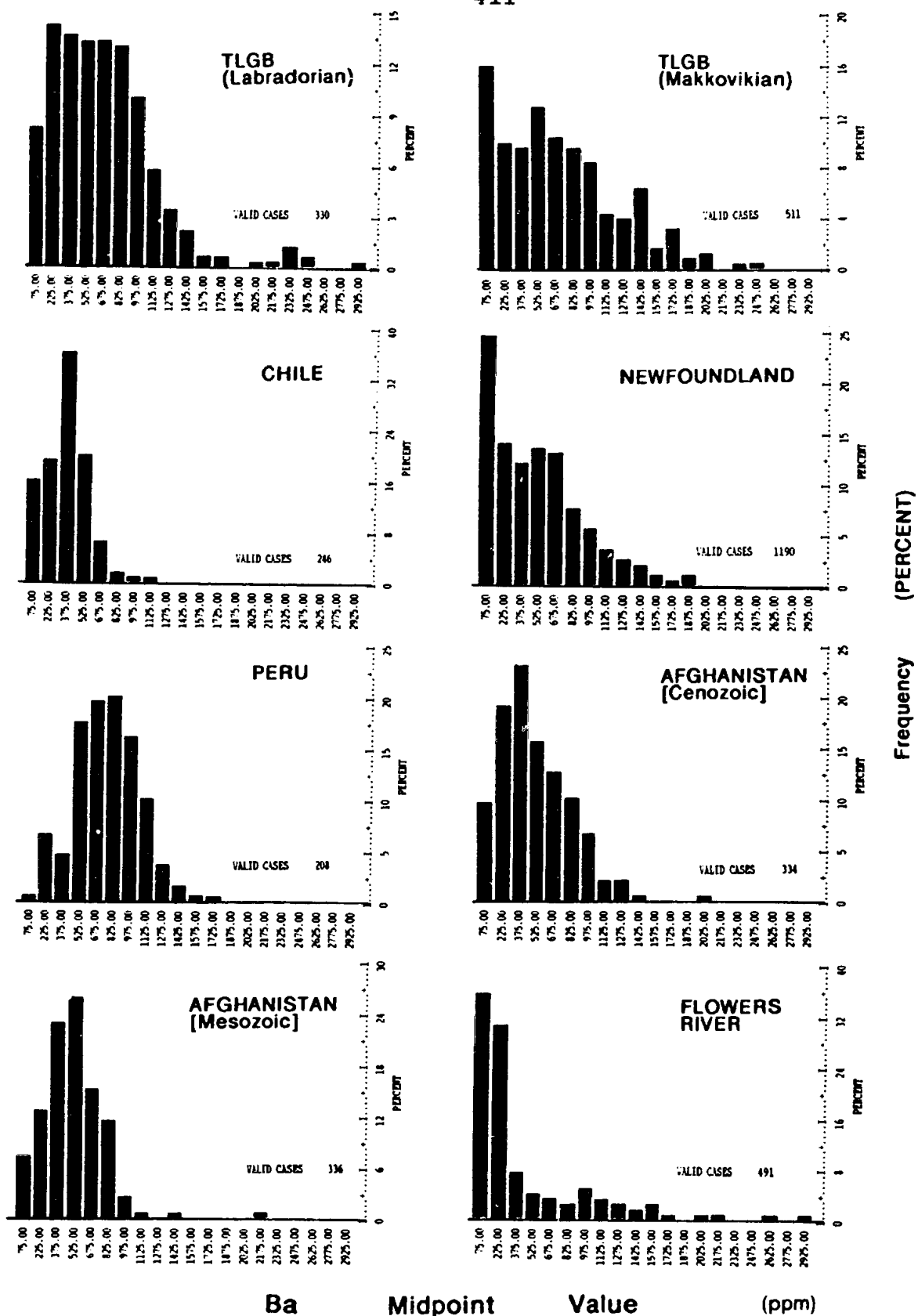Figure 9.13c. Comparative zirconium (Zr) frequency spectra.

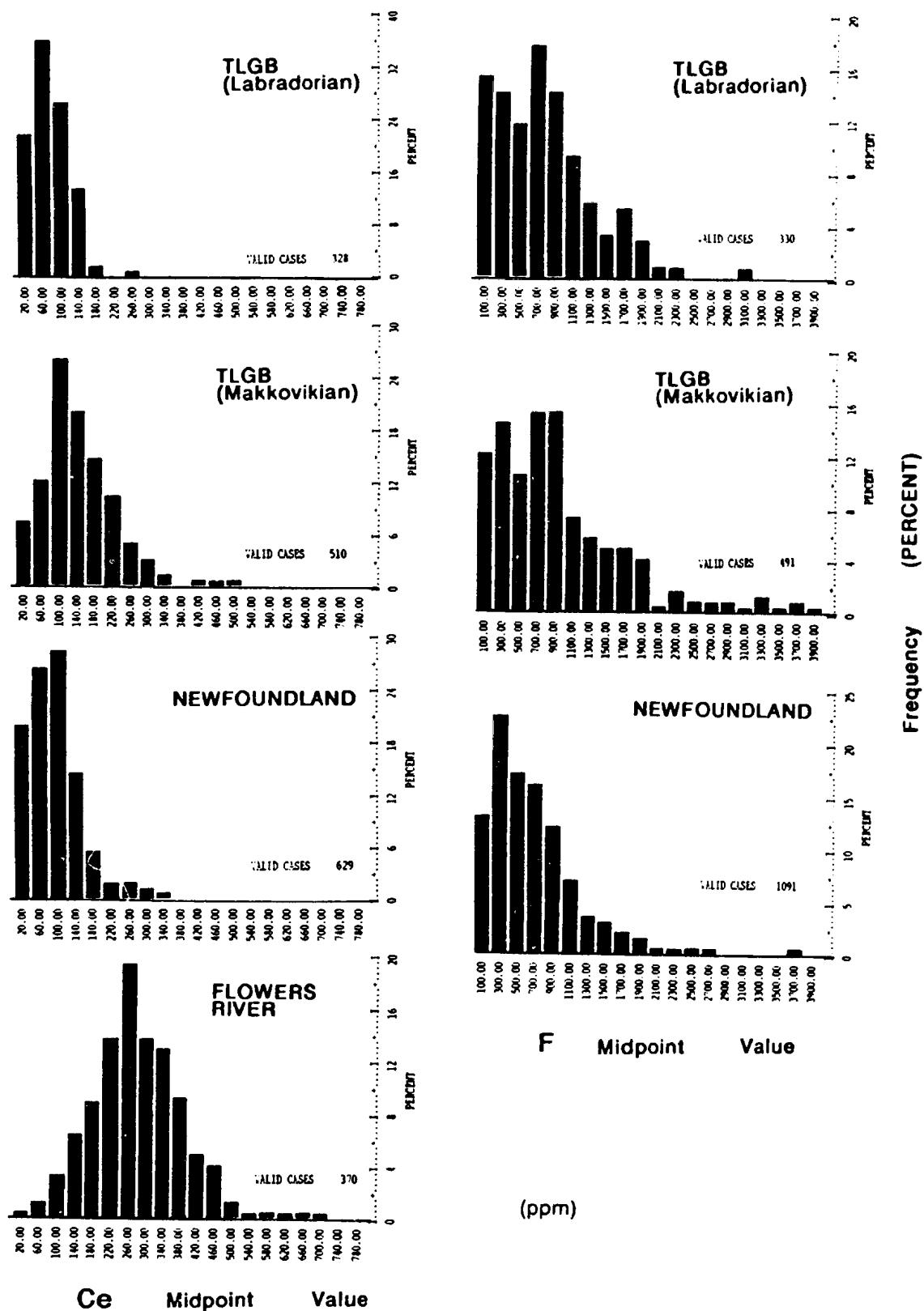Figure 9.13d. Comparative barium (Ba) frequency spectra.

Figure 9.13e. Comparative cerium (Ce) and fluorine (F) frequency spectra.
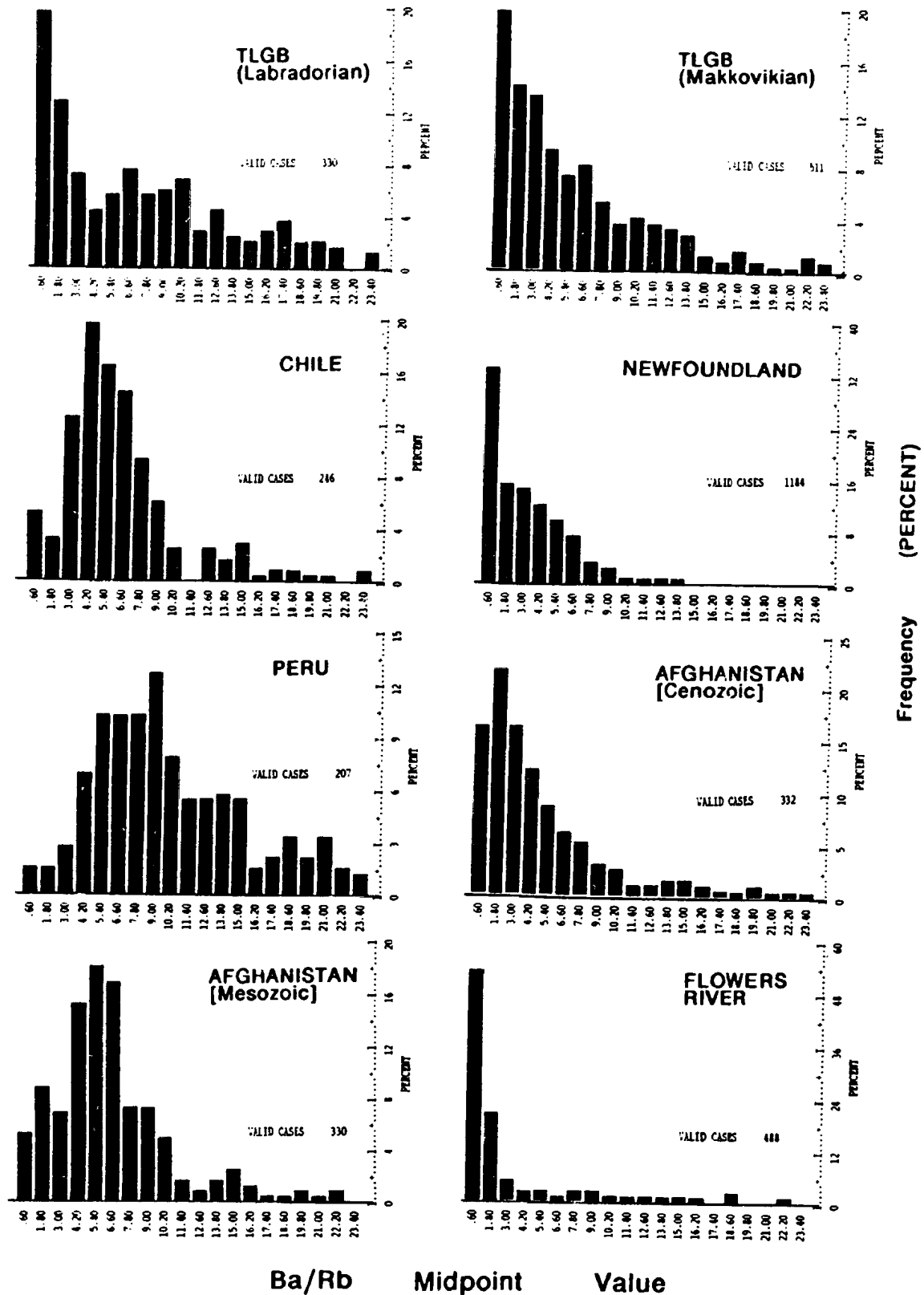
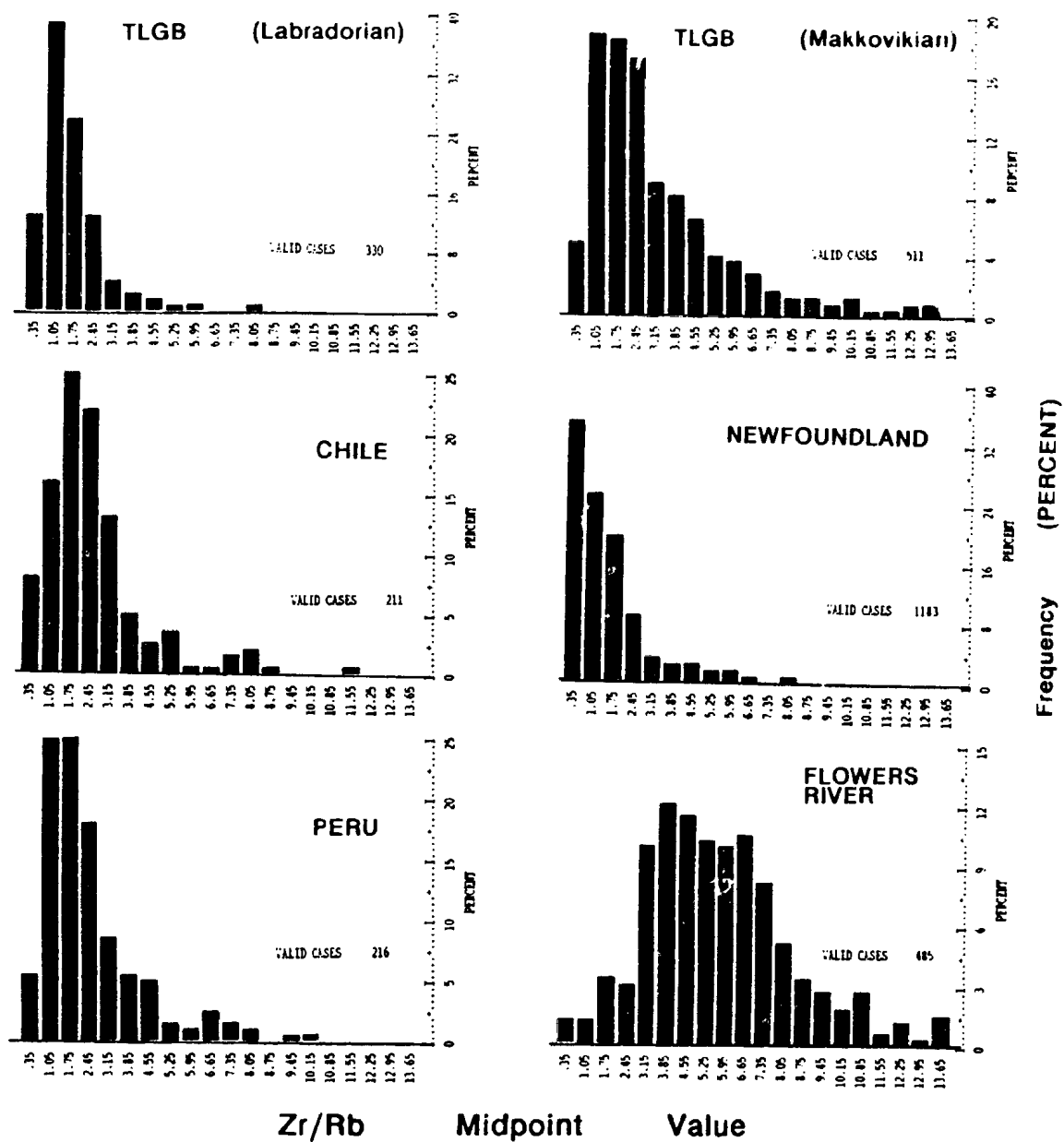Figure 9.13f. Comparative Ba/Rb frequency spectra.

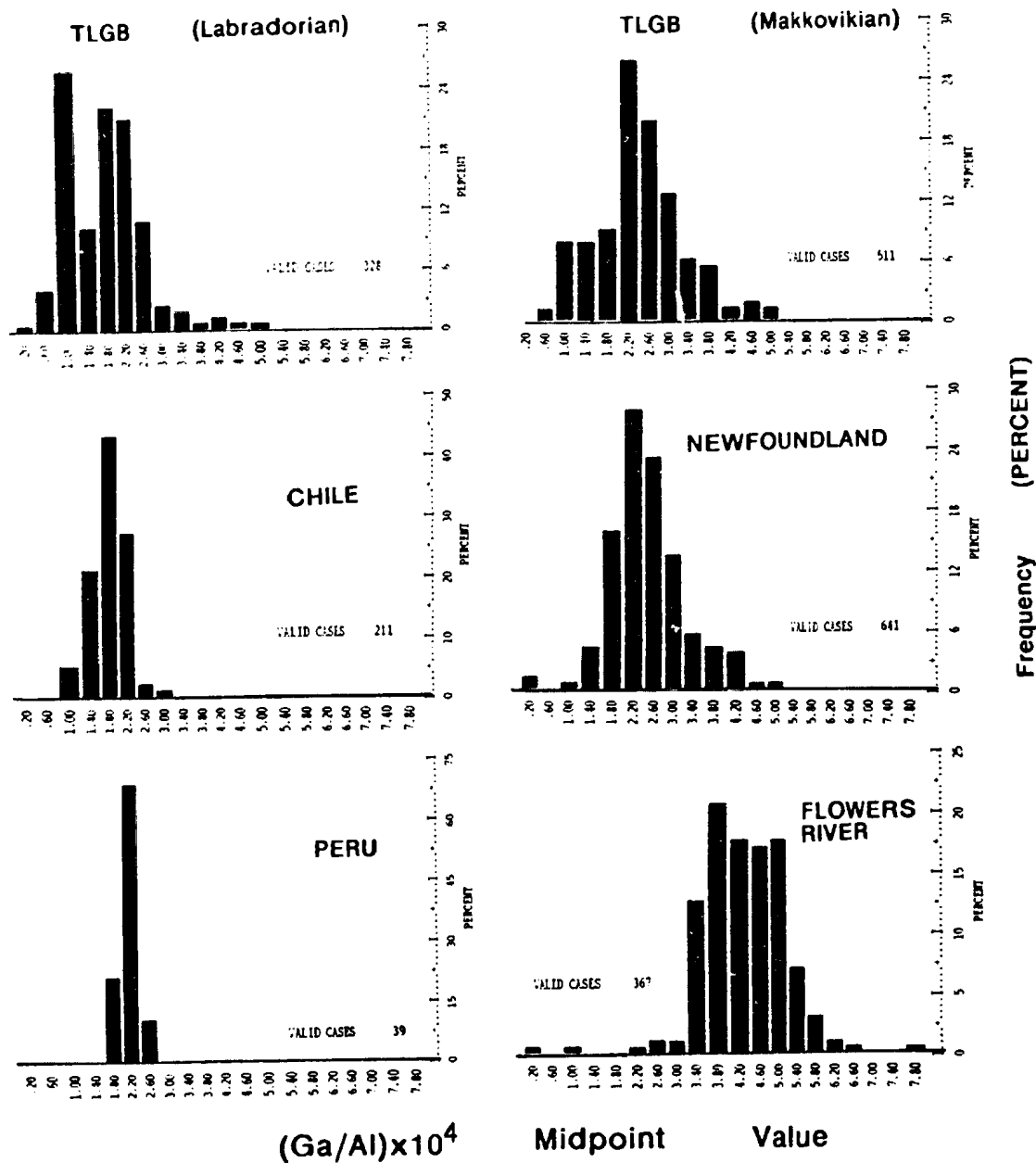Figure 9.13g. Comparative Zr/Rb frequency spectra.

Figure 9.13h. Comparative Ga/Al x 10⁴ frequency spectra.

normal or negatively-skewed patterns. Makkovikian and
collisional assemblages show general similarity, but the
former have slightly lower median Rb contents. The
Labradorian spectrum resembles those of arc assemblages,
but includes more Rb-rich compositions.

Zirconium (Figure 9.13c) : Zr characterizes the
Flowers River assemblage very clearly. The Makkovikian
spectrum includes a greater proportion of high-Zr rocks
than the Newfoundland or Labradorian assemblages, but is
similar in shape to both. Zr does not discriminate arc and
collisional assemblages effectively. Zn and Y spectra (not
figured) are closely similar to Zr.

Barium (Figure 9.13d) : Ba provides poor distinction
of arc and collisional environments. Both Makkovikian and
Labradorian assemblages contain a higher proportion of
high-Ba compositions than either arc or collisional
assemblages. The former resembles the Newfoundland spectrum
in general shape.

Cerium and Fluorine (Figure 9.13e) : Data are
incomplete for these elements. Ce characterizes the Flowers
River assemblage, and partly discriminates the Makkovikian
and Newfoundland assemblages. Both TLGB assemblages have
higher median F contents than the Newfoundland assemblage.
The similarity in the Labradorian and Makkovikian patterns
is deceptive, as their F evolution trends are distinct.
(Figure 9.18; see below).

Trace Element Ratio Frequency Spectra

Ba/Rb ratios (Figure 9.13f) : These elements behave
in contrasting fashions in arc and collisional assemblages
(see also Figure 9.17). Collisional and anorogenic
assemblages (characterized by Ba compatibility) have
positively-skewed log-normal spectra, and lower median
values than arc assemblages. The Makkovikian spectrum is
similar to collisional assemblages, but richer in high-Ba
compositions (see also Ba spectra).

Zr/Rb ratios (Figure 9.13g) : Zr/Rb offers little
distinction between Newfoundland and arc assemblages, but
characterizes Flowers River well. Zr/Rb spectra also
illustrate the Zr-enriched and slightly Rb-depleted nature
of much of the Makkovikian assemblage compared to
Newfoundland.

Ga/Al ratios (Figure 9.13h) : This parameter has been
proposed as a fingerprint of "A-type" granites (Collins et
al., 1982; Whalen et al., 1987), and characterizes the
Flowers River assemblage well. The Makkovikian and
Newfoundland assemblages are closely similar.

9.3.2 Trace Element Discrimination Diagrams

Tectonic Setting Discrimination Diagrams

The Rb - (Y + Nb) diagram (Figure 9.14a) of Pearce et
al. (1984) demonstrates a marked contrast between
Makkovikian and Labradorian assemblages, which plot mostly
in WPG (within-plate granite) and VAG (volcanic arc
granite) fields respectively. There is some overlap in the
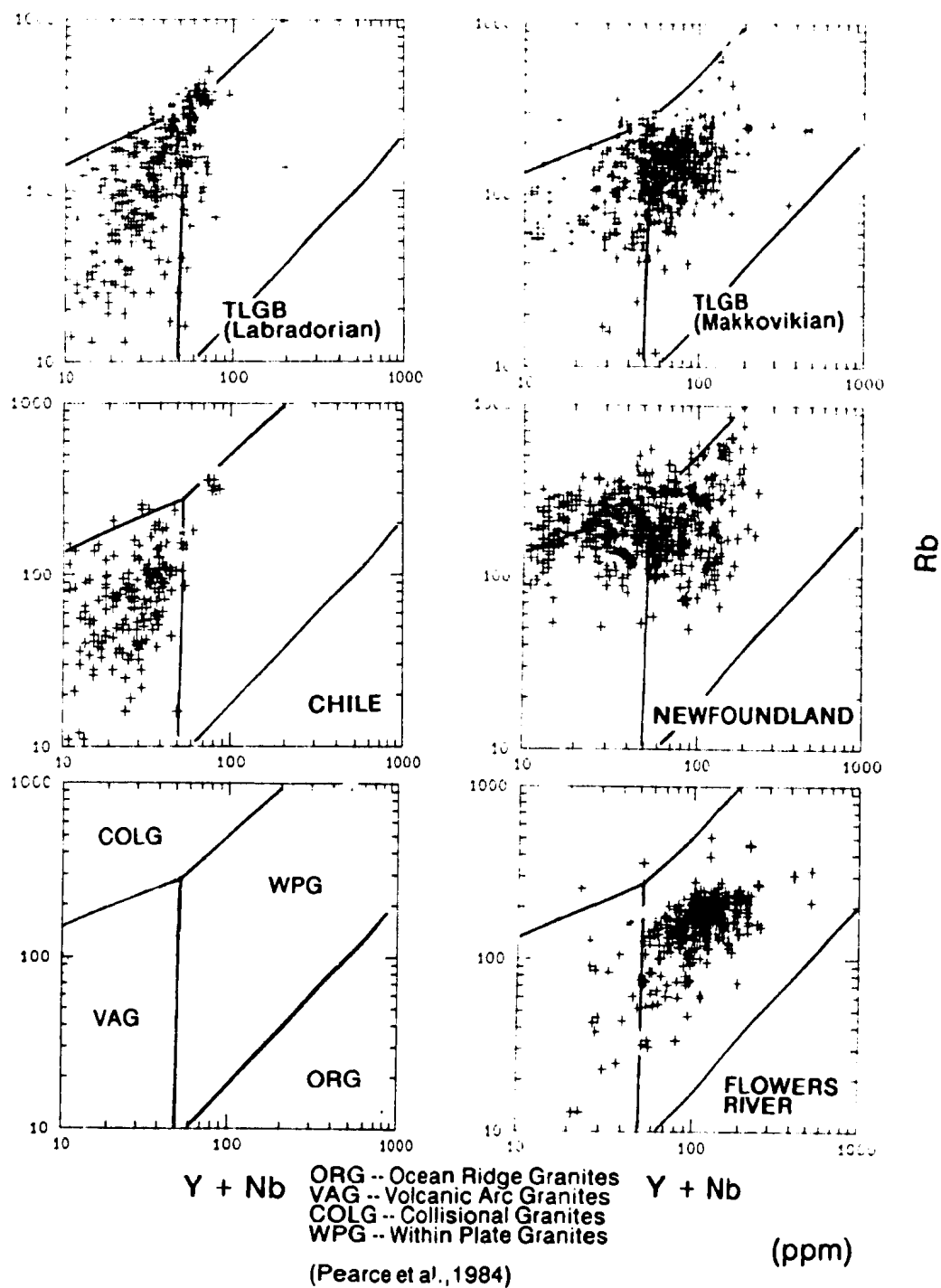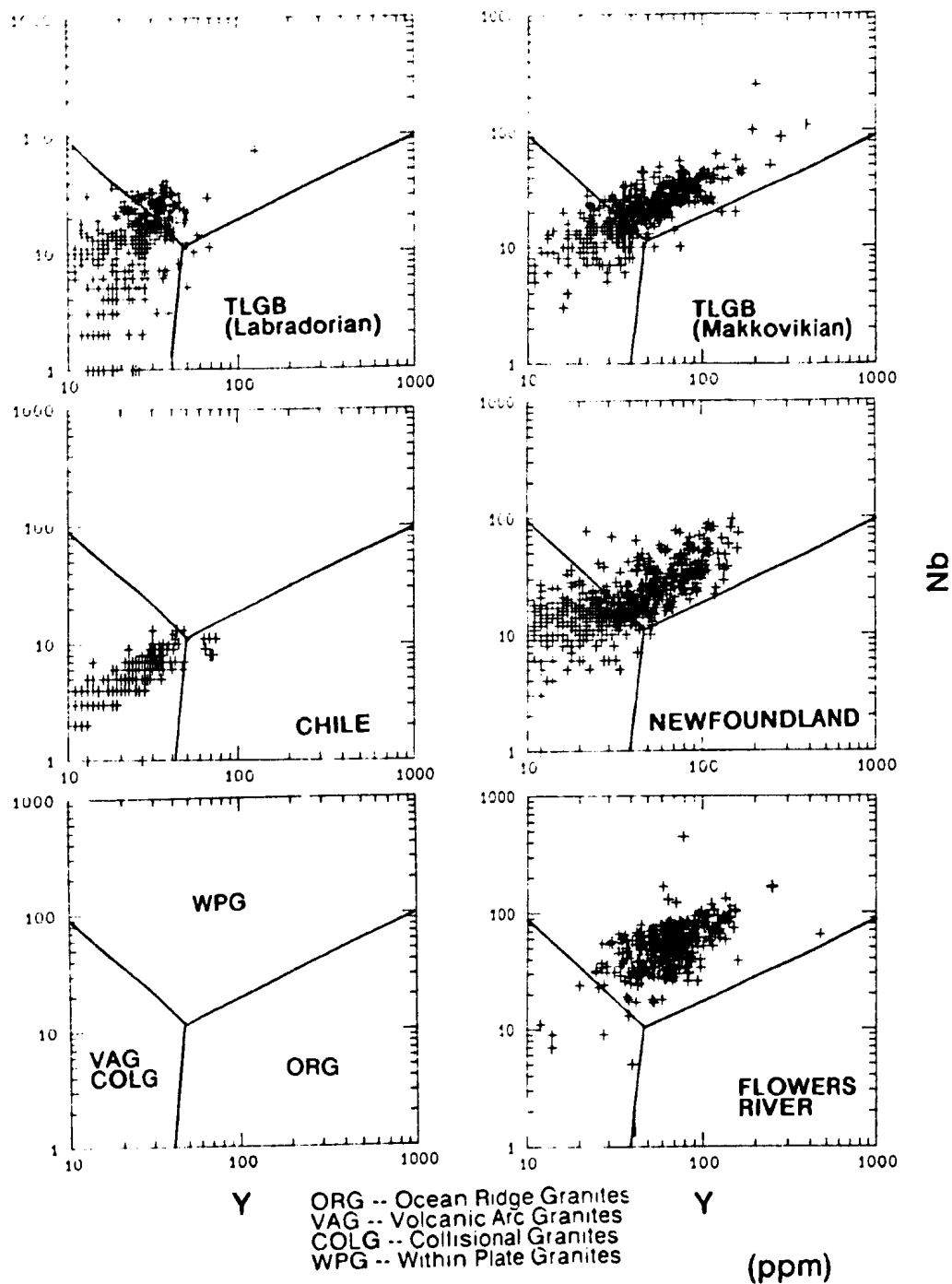
Figure 9.14a. Rb - (Y + Nb) discrimination diagrams (after Pearce et al.,1984) for TLGB and comparative assemblages.

Figure 9.14b. Nb - Y discrimination diagrams (after Pearce et al.,1984) for TLCB and comparative assemblages.
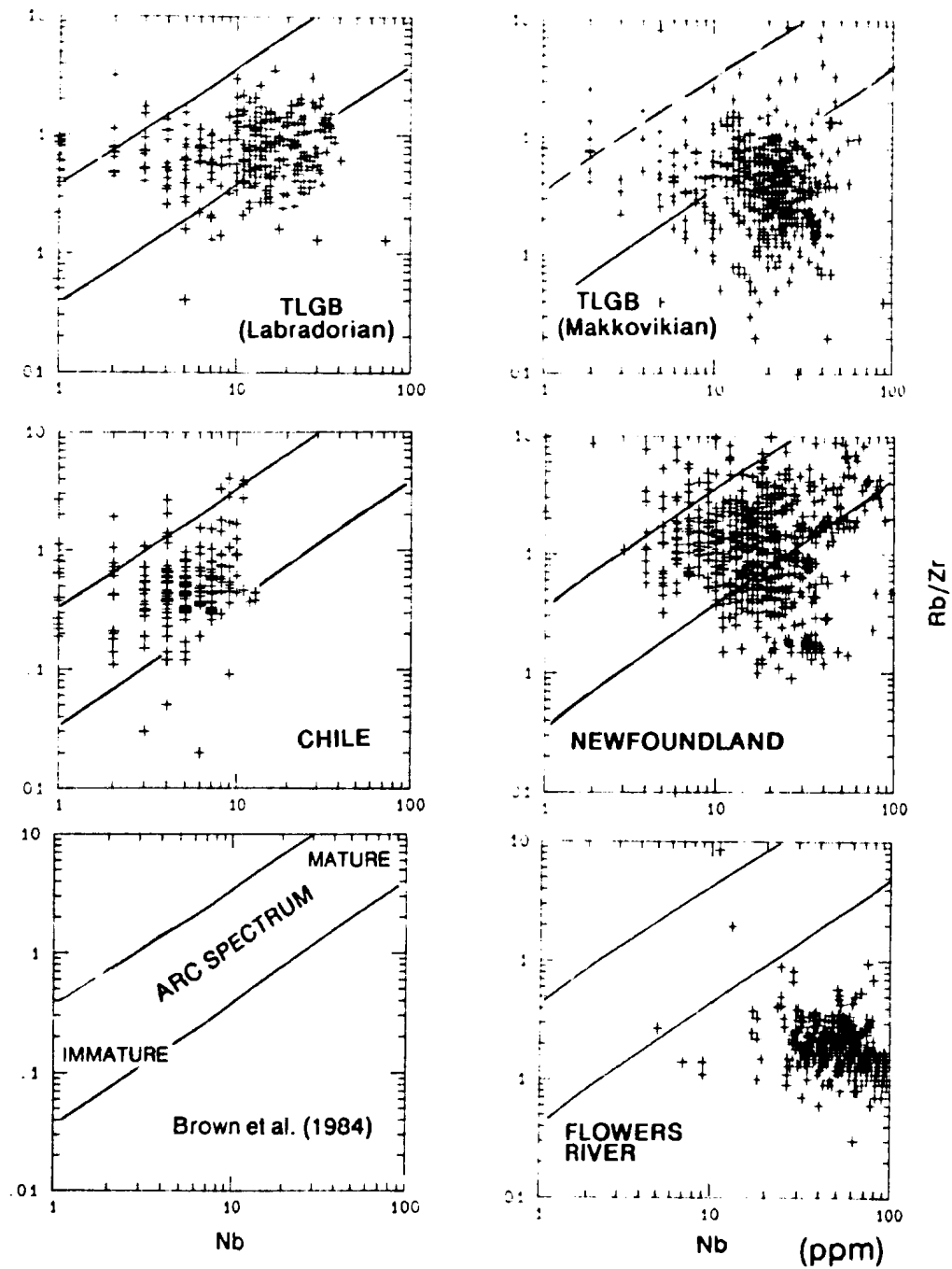
Figure 9.15. Rb/Zr - Nb discrimination diagrams (after Brown et al., 1984) for TLGB and comparative assemblages.

VAG field, and at the "triple point", but the TLGB (as a whole) lacks significant data within the COLG (collisional granite) field. However, the latter is primarily defined using syn-collisional suites; post-collisional suites (Harris et al., 1984) cannot be classified effectively in this system. This is shown well by Newfoundland data, which are smeared across all three fields. The Chile and Flowers River assemblages are correctly classified as VAG and WPG respectively. The Nb - Y diagram (Pearce et al., 1984) provides essentially the same divisions (Figure 9.14b), but shows greater overlap between TLGB assemblages.

In the Rb/Zr - Nb diagram (Figure 9.15) of Brown et al. (1984), the Labradorian assemblage lies partly within the mature portion of the arc spectrum, and corresponds to the most evolved Chilean data. The Makkovikian assemblage lies mostly below the arc spectrum, reflecting its Zr enrichment; a similar, but much more extreme, distribution is shown by Flowers River. The Newfoundland assemblage is widely scattered, but more strongly biased towards the mature arc area than Makkovikian granitoids.

Discrimination Diagrams for Identification of A-type Granites

Whalen et al. (1987) propose methods for separation of "A-type" granites from other evolved granitoid rocks. Their Zr - Ga/Al diagram (Figure 9.16a) discriminates Makkovikian and Labradorian assemblages, which fall predominantly in "A-type" and "Other" fields respectively. The Flowers River assemblage, however, has significantly higher Ga/Al and Zr than either Makkovikian or Newfoundland assemblages (see also Figure 9.13). The (K_2O+Na_2O / CaO) - $(Zr + Y + Nb + Ce)$ diagram (Figure 9.16b) provides less effective
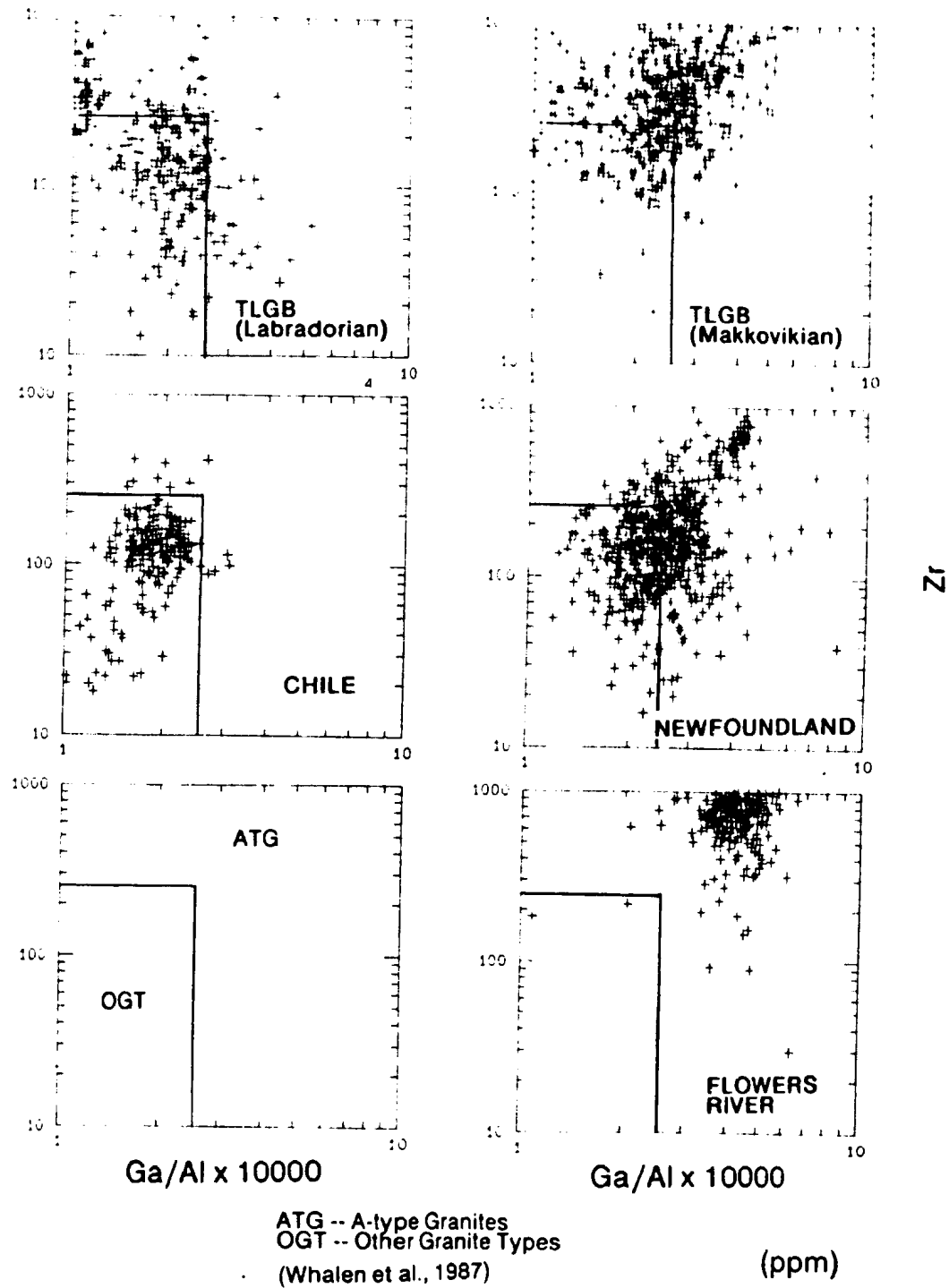
Figure 9.16a. Zr - Ga/Al discrimination diagrams (after Whalen et al, 1987) for TLGB and comparative assemblages.

ATG -- A-type Granites
OGT -- Other Granite Types
FGT -- Fractionated Granite Types

(ppm)
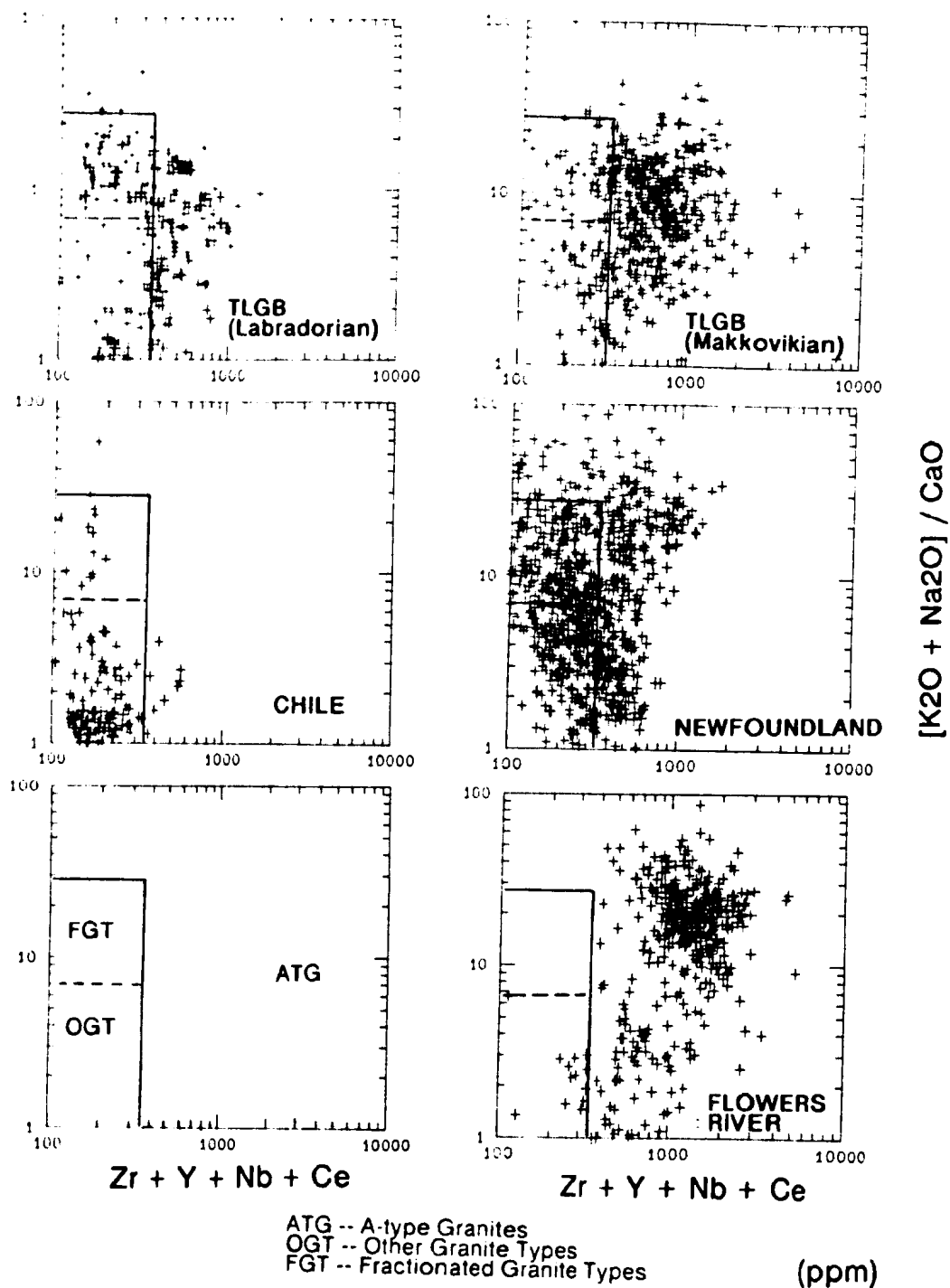
(Whalen et al., 1987)

Figure 9.16b. [(K₂O+Na₂O)/CaO] - [Zr+Y+Nb+Ce] discrimination diagrams (after Whalen et al, 1987) for TLGB and comparative assemblages.

discrimination, but classifies Makkovikian and Flowers
River assemblages as A-type granites. The definition and
significance of so-called "A-type" granites is a subject of
discussion (e.g. Whalen et al.,1987), but there is no doubt
that many Makkovikian granitoid rocks belong to this
category on the basis of these parameters.

9.3.3 Evolutionary Trends

Trace element evolution trends were assessed by
aggregating data into 5% SiO_2 intervals (Figure 9.17), as
described above for major elements. Problems caused by
outlying data at extreme SiO_2 contents are more acute for
trace elements; this applies particularly to the
Makkovikian assemblage at 50% SiO_2, which is biased by
two cumulate rocks with very high Zr, Y and REE reflecting
concentration of accessory minerals. These aberrant points
have been ignored in constructing trends.

Ba evolution varies widely. Both Labradorian and
Makkovikian assemblages have convex-upward trends reaching
peak Ba contents of 1000-1500 ppm Ba at 55-60% SiO_2. Arc
assemblages have largely incompatible Ba behaviour up to
70-75% SiO_2, but variable Ba content at a given SiO_2
value. Newfoundland and Flowers River assemblages both show
inversion of Ba behaviour at ca. 60% SiO_2, similar to the
TLGB trends. This contrast reflects the "early"
fractionation of K-feldspar in these potassic suites
compared to the relatively sodic arc assemblages.

Sr trends in arc assemblages are remarkably similar.
Both TLGB assemblages are enriched in Sr below 60% SiO_2
compared to all other areas, except Afghanistan Cenozoic
granites. Both Ba and Sr are sensitive to changes in
feldspar stability, which depend on a variety of factors,

Figure 9.17. Trace element evolution trends for the TLGB and comparative assemblages, expressed as mean compositions for 5% SiO$_2$ intervals.
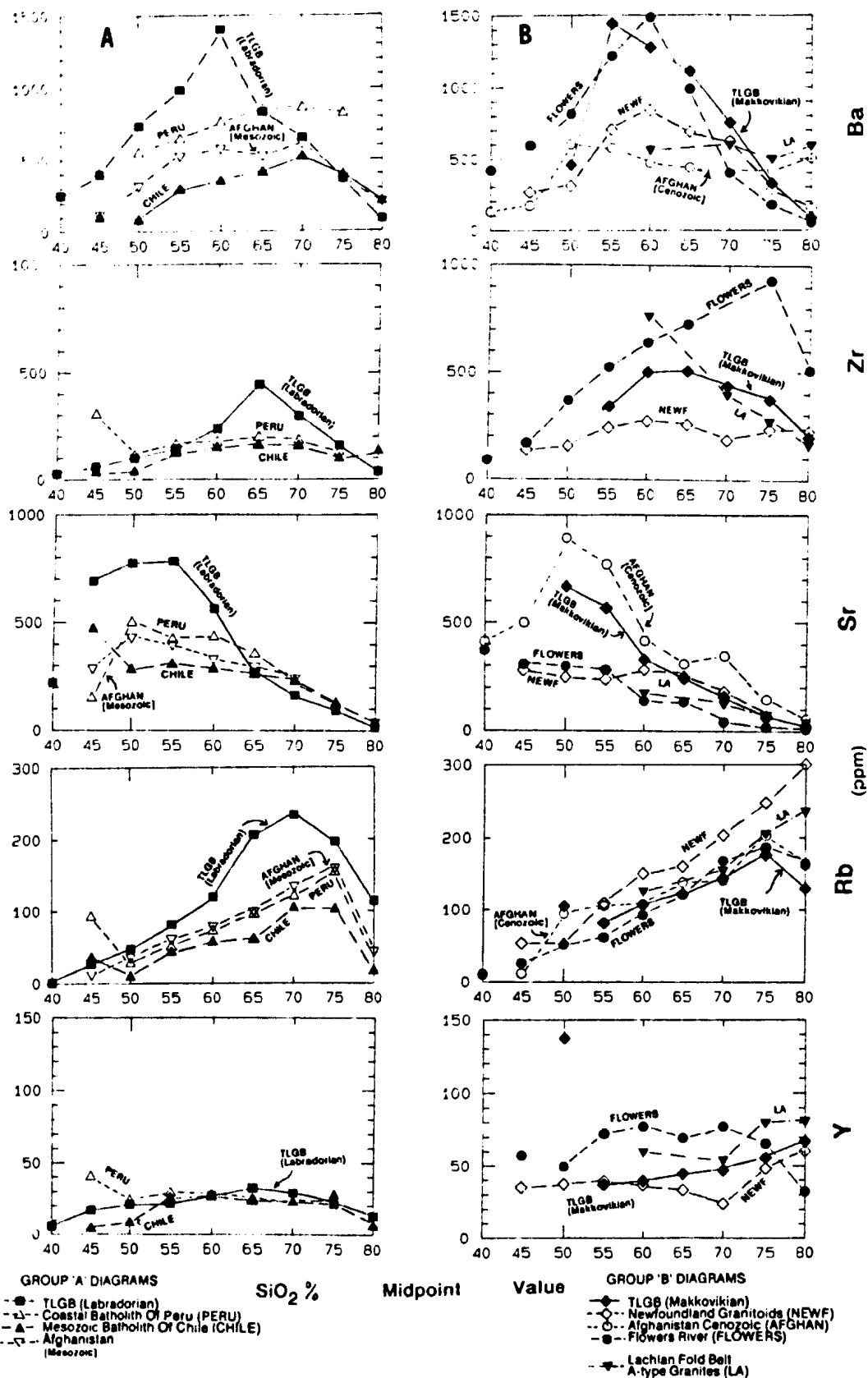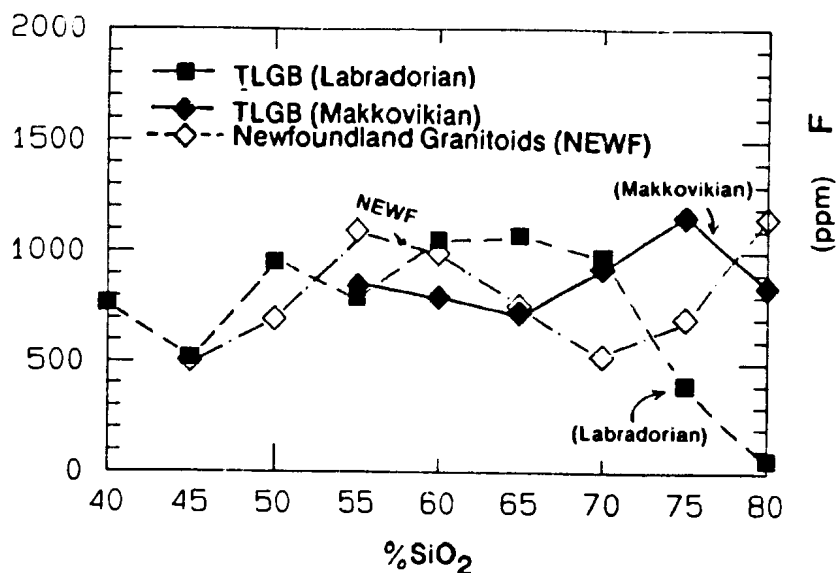
Figure 9.17 (continued) . Fluorine (F) evolution trends for TLGB and Newfoundland assemblages

including pressure and H_2O content. Although absolute values vary widely, the contrasting trends appear to be viable discrimination methods. Despite its use in discrimination plots (e.g. Figure 9.14), Rb shows little systematic variation between assemblages.

Zr and Y trends amplify contrasts noted in frequency spectra and discrimination diagrams (see above). Flowers River is strongly enriched at all SiO_2 contents; lesser enrichment is shown by the Makkovikian assemblage. Similar patterns are shown by Zn and REE (not figured). The Labradorian trend is similar to arc assemblages, except for a Zr peak at 65% SiO_2 that represents part of the Mount Benedict Intrusive Suite. Note the similarity between A-type granites of the Lachlan fold belt and parts of the Makkovikian assemblage.

The Makkovikian assemblage shows strong F enrichment above 70% SiO_2 compared to the Labradorian and Newfoundland assemblages (Figure 9.17). Depletion of F is evident amongst Labradorian high-SiO_2 granites compared to their Makkovikian counterparts.

9.4 SUMMARY and DISCUSSION

9.4.1 Evaluation of Geochemical Discrimination Methods

Frequency spectra for major element parameters such as SiO_2, TTDI, F/F+M, N/N+K, Agpaitic Index and A/C+N+K, discriminate volcanic-arc, collision-zone and within-plate settings effectively (Figures 9.6; 9.7). Martin and Piwinski (1972) and Petro et al. (1979) previously suggested that "compressional" and "extensional" environments could be discriminated via SiO_2 or TTDI spectra. It is suggested here that different types of "compressional" environment may also be resolved effectively by use of a wider range of parameters.

Frequency spectra for trace elements are less effective in dividing the compressional assemblages into arc and collisional environments. However, several elements, in particular Zr, Y and Zn, and the ratios Zr/Rb and Ga/Al, characterize within-plate granites of the Flowers River assemblage very clearly (Figure 9.13). The contrasting behaviour of Ba with differentiation appears to be the most consistent trace element parameter for distinction of arc and collisional assemblages.

Trace element discrimination diagrams suggested by Pearce et al. (1984) also distinguish arc and within-plate assemblages well, but encounter problems with the Newfoundland assemblage. They also simplify relationships, e.g. by suggesting a much closer affinity between the Makkovikian and Flowers River assemblage than indicated by spectral comparisons (see below). They are certainly useful, but are best used in combination with other types of data that emphasize extensive parameters.

A criticism that may be levelled at all empirical comparisons is that reference databases may not be truly representative of a specific environment. This is most acute for within-plate assemblages, represented here by only one database of Proterozoic, rather than Phanerozoic age. However, where environments are duplicated, as in arc assemblages, frequency spectra are internally consistent (Figures 9.6; 9.7; 9.13).

A second problem exists with respect to space - time - composition trends in arc environments (Brown, 1981; Brown et al.,1984), which migrate to siliceous, potassic compositions with age (maturity) and distance from the locus of subduction, and possibly in response to changes in subduction angle (e.g. Pankhurst et al., 1988). The Andean-Cordilleran arc assemblages used in this study are located close to subduction zones, and probably do not represent the full range of arc compositions. The generally more evolved composition of the Afghanistan (Mesozoic) assemblage relative to Peru and Chile (Figures 9.6; 9.7) may reflect preservation of both proximal and distal arc granitoids in Afghanistan, where these batholiths have been deformed and presumably telescoped. Such considerations are particularly important in interpretation of the Labradorian assemblage (see below).

Variations in the fourth dimension may be equally significant in assessing collisional zone magmatism. In the Appalachians, magmatism continued for up to 100 Ma after the Taconic orogeny (Colmann-Sadd, 1982; Williams et al., 1989; Figure 9.4). In the Himalayas, collision occurred a mere 50 Ma ago, and it is probable that some post-collisional suites are not yet generated or emplaced or exposed. There are also significant differences in erosion level between recent and ancient collisional belts, which complicate direct comparisons between them.

9.4.2 Geochemical Affinity of the Makkovikian Assemblage

Major Element Characteristics

The Makkovikian assemblage shows a number of distinct features. The most important of these are generally high SiO_2 and (particularly) TTDI values, indicating evolved compositions, depletion in CaO and MgO, high K+N/A and F/F+M indices at all SiO_2 contents, and a notable absence of peraluminous compositions. Comparative frequency spectra (Figures 9.6; 9.7) illustrate these characteristics well, and set the Makkovikian assemblage apart from comparative assemblages, with which there is no exact correspondance.

It is clear, however, that there are fundamental contrasts between these rocks and volcanic arc assemblages, as represented by data from California, Chile and Peru. The latter are dominated by intermediate SiO_2 contents, show much higher CaO and MgO and, most importantly, have low N/N+K and K+N/A indices that emphasize their relatively sodic and alkali-depleted compositions.

There is a much closer affinity between the Makkovikian assemblage and post-orogenic, broadly "collisional" assemblages from Afghanistan and (particularly) Newfoundland. Frequency spectra for SiO_2, MgO, CaO, TTDI and N/N+K are similar for all three assemlages. There are, however, contrasts in K+N/A, A/C+N+K and F/F+M frequency spectra and trends. The Makkovikian assemblage has higher K+N/A and F/F+M at all SiO_2 contents, indicating a tendency towards agpaitic and Fe-enriched behaviour during evolution. It also has very few peraluminous compositions compared to Newfoundland and (particularly) Afghanistan assemblages, and shows a quartz-poor evolution trend characterized by the presence of monzonite and syenite.

Within-plate assemblages (represented here by Flowers River) show extremely agpaitic and Fe-enriched tendencies, and are of much more restricted composition than the Makkovikian assemblage. Nevertheless, the Makkovikian assemblage has some affinity to them.

In summary, the Makkovikian assemblage most closely resembles the Newfoundland assemblage, but is transitional towards the agpaitic and alkalic granitoid rocks of Flowers River. This is shown well by evolution trends (Figures 9.10; 9.11) where the Makkovikian trend lies between the Newfoundland and Flowers River trends for most parameters.

Trace Element Characteristics

V, Rb and Ba frequency spectra, and Ba evolutionary trends, suggest contrasts between the Makkovikian and volcanic arc assemblages, but show greater overlap than major element parameters. Zr, Ce, Zr/Rb and Ga/Al frequency spectra illustrate the distinctive character of the Flowers River assemblage, which is enriched in all these parameters. In general, there is a very good correspondence between the Makkovikian and Newfoundland assemblages. However, the former shows some relative enrichment in Zr, Ce and Y, but falls well short of the strongly enriched Flowers River assemblage. Such characteristics are in agreement with the transitional major element characteristics noted above.

Trace element discrimination diagrams demonstrate clear contrasts with volcanic-arc assemblages, and suggest a general affinity to within-plate granitoid suites. The similarity to the Newfoundland assemblage is maintained, but Makkovikian granites are more strongly biased towards the within-plate field. The Makkovikian assemblage also

corresponds in part to "A-type" granite suites, as defined
by Collins et al.(1982) and Whalen et al.(1987), although
it does not show the strong HFS element, REE and Ga
enrichment of Flowers River, also clearly of A-type
affinity. Evolutionary trends resemble those of A-type
granites from the Lachlan fold belt in Australia.

Conclusions

The Makkovikian assemblage is best described as
transitional between collisional and within-plate
assemblages, as represented here by Newfoundland and
Flowers River respectively. Some discrimination diagrams
indicate a strong affinity to the latter, but this is
misleading, as its extreme trace element compositions are
rarely observed in Makkovikian granites. Major and trace
element frequency spectra closely resemble Newfoundland,
with the exception of F/F+M, A/C+N+K and K+N/A (see below).

The temporal setting of the Makkovikian assemblage is
also consistent with the syn- to post-orogenic environment
of the Newfoundland assemblage. Post-tectonic Makkovikian
granites were emplaced within a 50-80 Ma[*] period
following final deformational events, a period of time that
is similar to the 100 Ma (Silurian to Carboniferous)
duration of post-Taconic Appalachian plutonism.

The systematic differences between the Makkovikian
assemblage and this possible Phanerozoic analogue must,
however, be explained in any model of their development.

* NOTE : *The ca. 1720 Ma U-Pb age for the Cape
Strawberry Granite obtained just prior to submission (Krogh
et al., in prep.) indicates that Makkovikian plutonism
continued for at least 80 Ma after final deformation.*

Agpaitic and Fe-enriched tendencies may indicate
different source materials and/or different conditions in
their environment of generation. Granites of "supracrustal"
or S-type affinity, widely viewed as derivatives of
sedimentary rocks, are noticeably absent from the
Makkovikian assemblage. Such absence may indicate an
absence of such sources, which has obvious implications for
plate tectonic models involving destruction of oceanic
basins and attendant sedimentary basins. These problems,
and possible models, are discussed in Chapter 10.

9.4.3 Geochemical Affinity Of The Labradorian Assemblage

Major Element Characteristics

The Labradorian assemblage has expanded SiO_2, TTDI
and major element spectra that resemble (in terms of range)
arc assemblages from Peru and Chile. The Labradorian
assemblage, however, is bimodal, and includes few rocks in
the 55% to 67% SiO_2 range typical of these volcanic arcs.
Most major element frequency spectra indicate a relative
bias towards silicic, potassic compositions. The
Labradorian assemblage also has a quartz-poor
differentiation trend, and relatively high F/F+M and
agpaitic index values (at high SiO_2); such features
partly resemble the Makkovikian assemblage.

Trace Element Characteristics

Bimodal major element compositional spectra have widely
been proposed as hallmarks of anorogenic or within-plate
magmatism (e.g. Martin and Piwinskii, 1972; Petro et al.,
1979). However, trace element frequency spectra suggest no

affinity between Labradorian granites and those from Flowers River. Most resemble spectra from volcanic-arc suites such as Peru or Chile, although some also resemble Newfoundland. Granitoid rocks with enhanced levels of Zr, Y and REE (typical of the Flowers River and, to a lesser extent, Makkovikian assemblages) are not abundant.

An affinity to some arc assemblages is also suggested by discrimination diagrams, where the Labradorian assemblage lies mostly within the VAG (volcanic-arc granite) field of Pearce et al. (1984). In the terminology of Brown et al.(1984), the Labradorian assemblage lies at the "mature" end of the arc compositional spectrum. Relatively few Labradorian granites qualify as within-plate or A-type granites.

Affinity Of Labradorian Mafic and Intermediate Rocks

Labradorian granitic (s.s.) rocks could belong to any of the comparative assemblages (except Flowers River), and plot essentially at the triple point in trace element discrimination diagrams of Pearce et al.(1984). Mafic and intermediate rocks, however, generally have simpler differentiation histories than felsic intrusive rocks, and are thus more likely to preserve original geochemical contrasts (e.g. Pearce and Cann, 1973; Brown et al., 1984). Labradorian mafic-intermediate rocks are here defined simply as those with < 60% SiO_2.

Alkali-silica relationships (Figure 9.18a,b) and mean compositions (Table 5.5, p.231-232) indicate that these rocks correspond broadly to "shoshonites", and are enriched in K_2O relative to "normal" calc-alkaline compositions of similar SiO_2 content. A few fall within the field of alkaline volcanic rocks (Irvine and Baragar, 1971).

SHO - Shoshonites (Morrison, 1980)
ALK - Alkaline Basalts (Irvine and Baragar, 1971)
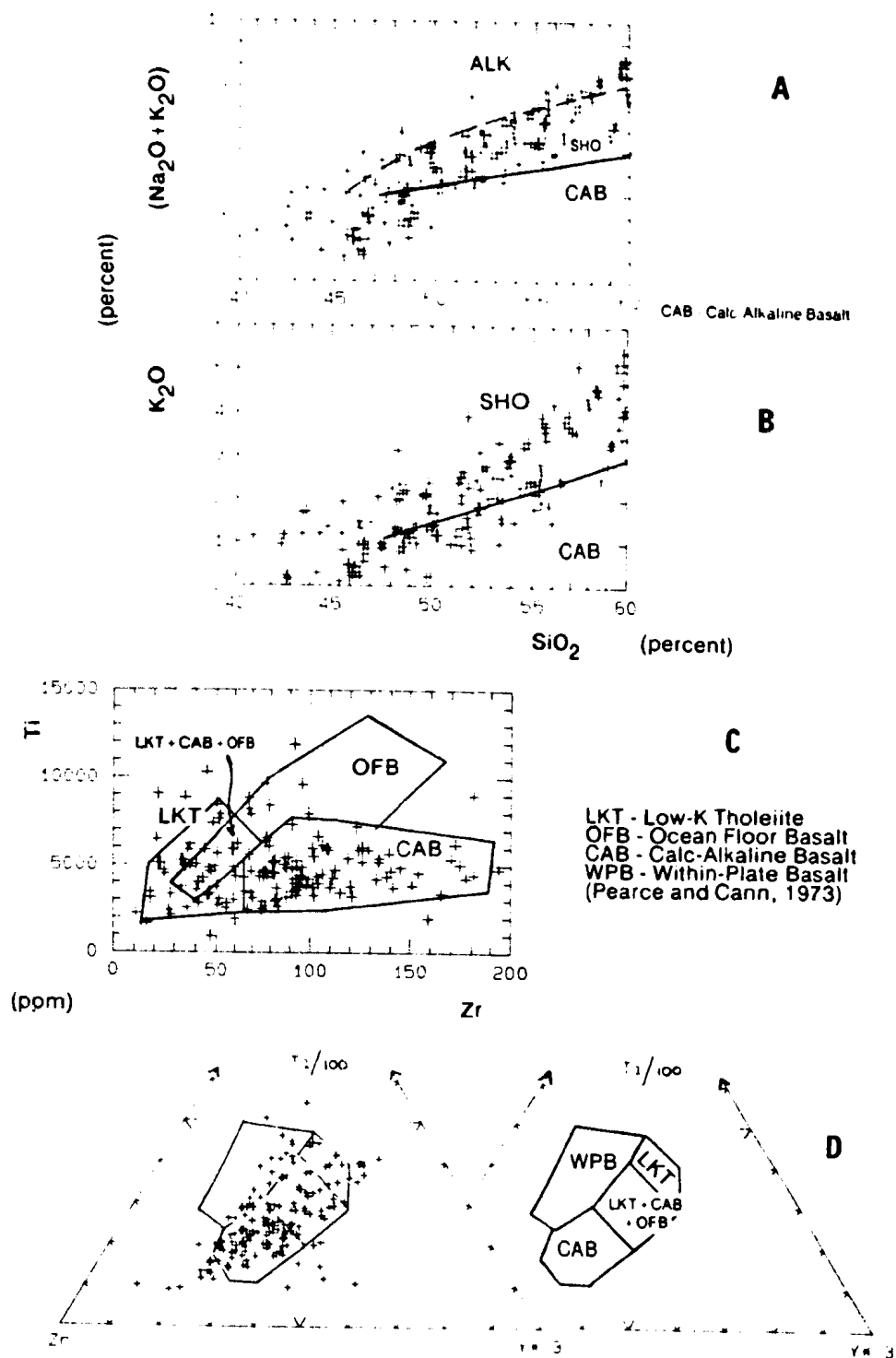

Figure 9.18. Characteristics of Labradorian mafic and intermediate intrusive rocks. (a) (Na_2O+K_2O) – SiO_2 diagram. (b) K_2O – SiO_2 diagram. Field boundaries from Irvine and Baragar (1971) and Morrison (1980). (c) Ti-Zr diagram. (d) Ti/100 – Zr – Y x 3 diagram. Field boundaries from Pearce and Cann (1973).

Trace element discrimination diagrams (Figure 9.18c,d) place Labradorian mafic rocks within LKT (Low-K tholeiite, typical of island arcs) and CAB (calc-alkaline basalt) fields (Pearce and Cann, 1973). A few are transitional to the WPB (within-plate basalt) field.

Discussion and Conclusions

Previous studies of Labradorian volcanic rocks (Ryan, 1984; Ryan et al., 1987) did not reach any firm conclusions regarding tectonic setting. Problems in classification remain partly unresolved, and the following discussion echoes some of their suggestions and viewpoints.

An anorogenic, within-plate setting is partially supported by bimodal SiO_2 and TTDI frequency spectra, and relatively high F/F+M and K+N/A in some granitic rocks (e.g. Martin and Piwinski, 1972; Petro et al., 1979). However, distinctive trace element patterns typical of granites in such settings (Anderson, 1983; Pearce et al., 1984) are absent. Also, although there is no evidence of orogeny in the study area, Labradorian deformation and metamorphism was widespread to the south (Wardle et al., 1986), and may be directly or indirectly connected to magmatism.

A second possibility is a distal ("mature") arc setting analogous to bimodal basalt-trachyte volcanism east of the main Andean volcanic arc or Cenozoic volcanism in the western U.S.A. Calc-alkaline to shoshonitic mafic rocks are important components of such mature arc assemblages (Morrison, 1980; Brown et al., 1984; Munoz and Stern, 1989). Labradorian granitoid rocks have more evolved compositions than proximal arc assemblages (e.g. Peru, Chile), which is consistent with a distal location. The

absence of regional Labradorian deformation in the study
area may thus be a consequence of its position relative to
active subduction.

A post-collisional setting is also possible, as
potassic magmatism in such settings overlaps geochemically
with the magmas of mature arcs (e.g. Pearce et al., 1984;
Brown et al., 1984). The 150 Ma interval between the
Makkovikian orogeny and Labradorian magmatism argues
against a post-orogenic relationship to this event, but the
ca. 1650 Ma deformation and high-grade metamorphism south
of the Grenville Front Zone (Wardle et al., 1986) may
record a collisional event outside the study area.

It is difficult to choose between the latter two
alternatives. Labradorian igneous rocks in the study area
are at the northern fringe of a much wider magmatic
province, probably do not record the full range of
compositions in this belt. This difficulty may be
resolvable via scrutiny of Labradorian granitoid rocks
within the high-grade terranes, particularly in terms of
their transverse compositional variations. The presence of
unidirectional compositional and isotopic trends, as
described by Brown (1981) and Brown et al.(1984) would
support a "mature-arc" tectonic setting.

This uncertainty does not, however, dissuade the author
from speculation in Chapter 10.

CHAPTER TEN
MAGMATISM AND CRUSTAL EVOLUTION
IN THE MAKKOVIK PROVINCE

Chapter Abstract

It is suggested that most Makkovikian magmas were generated as part of a complex syn- to post-orogenic process involving the emplacement of anhydrous, mantle-derived, mafic magmas into intermediate rocks of Archean and slightly older Proterozoic sialic crust. This interaction took place via coupled assimilation-fractional crystallization, and generation of and mixing with crustal anatectic melts. Anatexis took place under conditions where zircon and accessory phases were unstable. This is not compatible with the prevalent model for generation of other similar "A-type" granites, which invokes anatexis of previously dehydrated and melted lower crustal rocks. However, material of this type may have *contributed* to magma genesis

As a consequence of greater heat production in the Early Proterozoic Earth, mantle-derived magmas may have been high-temperature, high-Mg liquids of komatiitic affinity, which have enormous capacity for direct assimilation and thermal transfer. The transitional "anorogenic" affinity of the Makkovikian assemblage (and other Proterozoic granitoid suites) may thus be a consequence of the volume and characteristics of this subcrustal magma flux, rather than any one specific crustal source. In younger environments, such conditions only occur in zones of exceptionally high heat flow, such as rift zones related to thermal plumes in the mantle.

Labradorian magmatism is more difficult to model. A generally similar mantle-crust interaction model is proposed, but it is suggested that cooler, wetter, mantle-derived mafic magmas were generated by hydrous melting of peridotite, and thus had significantly less capacity for assimilation and thermal transfer. It is suggested that such magmas were generated by addition of volatiles (and recycled crustal material) to the mantle wedge overlying a subduction zone. Labradorian granites (s.s.) were probably generated by melting of Makkovikian lower crust with varied Nd isotopic characteristics under less extreme conditions, where zircon and refractory phases remained stable.

The presence of mantle-derived material in virtually all Makkovikia, and some Labradorian magmas supports the importance of Early Proterozoic crustal growth, as documented by other studies of the Northern Hemisphere American Precambrian. In this

case, however, at least some of this growth occurred in a
post-orogenic setting with many characteristics of "anorogenic"
magmatism. In addition to adding to the crust, these events
contributed to the gross compositional stratification that
appears to discriminate Proterozoic domains from undisturbed
Archean cratons.

A model is proposed where juvenile terranes generated in
ensimatic arc environments were accreted to the margin of the
North Atlantic Craton. The insulating effects of newly accreted
crust induced melting of the subjacent mantle, and underplating
of the crust by mantle-derived mafic magmas. This model resembles
several recent proposals for Precambrian and Phanerozoic magmas
of similar affinity. This protracted Makkovikian magmatism was
followed by the establishment of a new northward-dipping
subduction zone, of which Labradorian magmatism was a distal
manifestation. A possible younger analogue to these events took
place on the South American margin of Gondwanaland, where Andean
arc magmatism is partly superimposed on Late Paleozoic to Early
Mesozoic post-orogenic to "anorogenic" plutonism. The latter was
the final stage in the assembly of Gondwanaland, an event that
resembles the Proterozoic assembly of proto-Laurentia recently
proposed by Paul Hoffman.

On a broader scale, this model is consistent with recent
speculation concerning cyclic patterns in orogenic history, that
propose aggregation of continental plates over mantle
downwellings, followed by insulation of subjacent mantle, thermal
upwelling (leading to anorogenic magmatism) and (eventually)
rifting. In a hotter, Proterozoic Earth, the time-lag between
continental aggregation and mantle upwelling would be reduced,
and conditions analogous to those of "anorogenic" magmatism would
prevail in post-orogenic settings. Distinctions between
"post-orogenic" and "anorogenic" granitoid magmatism should
become increasingly blurred in Early Precambrian orogenic belts,
a prediction that that is consistent with the transitional
affinity of the Makkovikian assemblage, and Early Proterozoic
batholiths from other shield areas. Also, growth and vertical
reorganization of the continental crust by post-orogenic
magmatism may have been proportionally more important in a hotter
Earth, particularly during and following periods of continental
aggregation. This may (in part) explain the apparently high rates
of crustal growth calculated by some workers for this period in
Earth history.

Introduction

It is difficult to concisely summarize and synthesize
the varied information discussed in this thesis. The
characteristics of specific magmatic assemblages are
discussed in the concluding sections of previous chapters
and reviewed in individual chapter abstracts. This final
chapter is concerned with wider models for Lower
Proterozoic magmatism and crustal evolution in the Makkovik
Province.

The first two sections examine the petrogenesis of
Makkovikian and Labradorian magmatic assemblages. Source
materials, source regions and generative mechanisms are
evaluated and coordinated into petrogenetic models for
each. Some possible younger analogues for the Makkovikian
assemblage (in addition to those assessed in Chapter 9) are
discussed. The third section presents a model for crustal
evolution of the Makkovik Province, that integrates these
petrogenetic models and other information in a
plate-tectonic framework. Following this model, some
speculative discussion concerning the role of Proterozoic
magmatism in Earth evolution is presented, drawing upon
recent work concerned w..h long-term cyclic or secular
behaviour in tectonic processes.

The final section briefly reviews some avenues of
further investigation that could fill gaps remaining in
this study, or form future projects in their own right.
This is by no means an exhaustive list !

10.1 PETROGENESIS OF MAKKOVIKIAN MAGMAS

Summary of Important Characteristics

The syn- to post-tectonic Makkovikian assemblage is dominated by metaluminous to slightly peralkaline, siliceous, potassic, K-feldspar porphyritic, granite and alkali-feldspar granite, and volcanic equivalents (Chapters 3, 4 and 7). A subordinate (syn-tectonic) association consists of peraluminous granitoid rocks that appear, in some cases, to have been derived by anatexis of local country rocks. Both associations have evolved major element compositions, and the most "mafic" Makkovikian rocks are monzonite and syenite.

The dominant plutonic association shows variably agpaitic behaviour (K+N/A = 0.9 to 1.05) and Fe-enrichment (F/F+M > 0.85). Distinctive trace element features include enrichment in fluorine, HFS elements and REE (3.2, 3.3). These granitoid rocks qualify as "within-plate" or "A-type" granites in popular classifications (Chapter 9), but generally lack the extremely agpaitic compositions associated with peralkaline or undersaturated suites. A comparative analysis indicates that they are transitional in character between the post-orogenic, post-collisonal granitoid suites of the Newfoundland Appalachians, and true "anorogenic" suites such as Middle Proterozoic granites in northern Labrador (Chapter 9). They are distinct in all respects from volcanic arc suites such as Andean or Cordilleran batholiths.

Subordinate peraluminous granites have generally low ‾, HFS element and REE contents that indicate different sources and/or conditions of generation from the dominant association (3.2, 3.3). These are not <u>strongly</u> aluminous "S-type" granites (A/C+N+K > 1.1) in the sense of Chappell

and White (1974), and their peraluminosity is not
necessarily indicative of metasedimentary sources, except
in the case of the Pitre Lake Granite. As noted in Chapter
9, the Makkovikian assemblage is notably deficient in
strongly peraluminous compositions.

Source Materials and Source Regions

Isotopic Arguments : In the west of the area,
negative ϵ_{Nd}CHUR (-3 to -14) unequivocally indicates
older crustal material in Makkovikian magmas (8.2.2).
However, excluding one anatectic granite, their ϵ_{Nd}CHUR
is too high to permit derivation <u>entirely</u> by melting of
3100 - 2800 Ma old Archean crust, which would have
ϵ_{Nd}CHUR of -12 to -15 at 1800 Ma. Derivation by melting
of assorted 2600-2200 Ma old crust is unlikely, as there is
little evidence of activity during this period in Labrador.
It is therefore concluded that Makkovikian magmas in the
west are variable mixtures of juvenile (mantle-derived)
material and polycyclic Archean crust (8.3.2).

In the east, positive ϵ_{Nd}CHUR (+2 to +5), indicates
predominantly juvenile sources. Possible "basement" in the
east (Cape Harrison Metamorphic Suite) has ϵ_{Nd}CHUR of +2
to +3, and is thus unlikely to be older than ca. 2100 Ma.
The eastern plutons of the Strawberry Intrusive Suite were
isotopically identical to postulated depleted mantle at the
time of their emplacement. By analogy with compositionally
similar granites in the western domain, it is suggested
that these eastern domain magmas were also mixtures of
mantle and "sialic" crust (8.3.2). However, the sialic
crust in the east consists of Proterozoic material,
probably no older than 2100 Ma. The Cape Harrison
Metamorphic Suite is the best candidate for this older
pre-Makkovikian crustal component with a short crustal

residence period. The relative contributions of end-members are difficult to assess in the east, as there is little contrast in their Nd isotopic compositions (8.3.2).

There is clear isotopic evidence of an Archean crustal component in western plutons of the Strawberry Intrusive Suite. The mantle-like ϵ_{Nd}CHUR of the eastern plutons, however, indicates that any crustal component in them was extremely juvenile, and even the Cape Harrison Suite is unsuitable. A possible solution is that the "crustal" component in these magmas is the "juvenile" component derived from the mantle during slightly earlier Makkovikian magmatism. This is consistent with geochronological data indicating that the Strawberry Intrusive Suite is younger than other Makkovikian granites. (Krogh et al., in prep.)

Elemental Arguments : Several elemental geochemical arguments also suggest that Makkovikian magmas contained a mantle-derived component. Monzonite, quartz monzonite and syenite of the Long Island unit and (particularly) the Numok Intrusive Suite are impossible to derive by melting a crustal source of intermediate composition (Wyllie, 1984). These relatively low-SiO_2 rocks have higher Sr and Ba contents than any comparative assemblage (9.3.1, 9.3.3). Such features are inconsistent with partial melting of a feldspar-bearing source, and suggest contributions from mafic magmas derived from the mantle, where partial melting and subsequent fractionation would act to enrich both Ba and Sr.

As a counter argument, many Makkovikian granites are close to ternary minimum compositions in the granite system (Figure 3.6, p.81; Figure 4.5, p.136) and could be derived by crustal anatexis. Their evolutionary trends, however, lie close to the plagioclase - K-feldspar cotectic surface, indicating that at least some evolved to eutectic

compositions via fractional crystallization. Trace element
trends in most units are consistent with evolution by
plagioclase and K-feldspar (± mafic mineral) fractionation,
which also suggests a non-eutectic parental magma
composition, possibly monzonitic to syenitic. Such features
argue against wholly crustal sources for Makkovikian
granites, although they may have partly originated in the crust.

HFS element and REE enrichment in Makkovikian magmas
(3.2; 4.2) indicate that zircon, sphene and other accessory
minerals were not present as residual material in their
sources. This is consistent with a significant
mantle-derived component and/or breakdown of these phases
during crustal anatexis. The latter probably requires high
temperatures, in excess of $850^{o}C$ (e.g. Whitney, 1988;
Clemens et al., 1986), but may also be facilitated by
fluorine, which encourages complexing of HFS elements and
REE (Harris and Marriner, 1980; Collins et al., 1982;
Whalen et al., 1987). Halogens may be introduced as a
volatile flux associated with a mantle-derived component
(e.g. Harris and Marriner, 1980), or released by hornblende
breakdown, which also requires high temperatures (Wyllie,
1984, Whitney, 1988). The presence of fluorine during
subsequent high-level fractional crystallization would also
inhibit accessory mineral crystallization, leading to HFS
element and REE enrichment.

Petrogenetic Model -- General Features

It is proposed that most Makkovikian magmas were
generated by thermal and chemical interaction between
anhydrous, mantle-derived, mafic magmas and lower crustal
rocks of generally intermediate composition (Figure 10.1).
Similar models have been proposed elsewhere (Barker et al.,
1975; Hildreth, 1981; Fyfe, 1988, Hildreth and Moorbath,
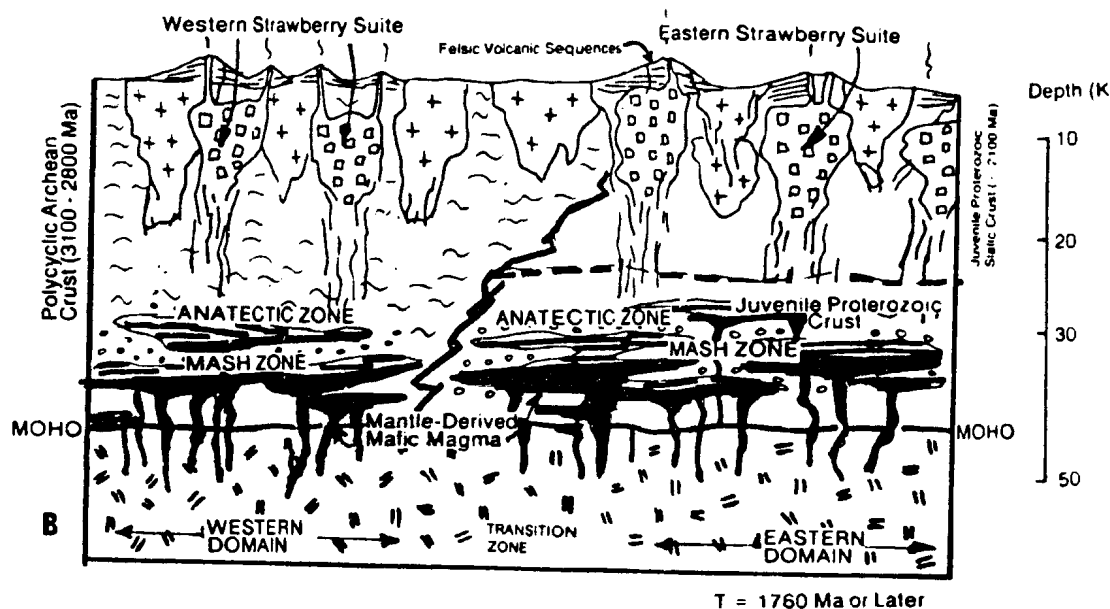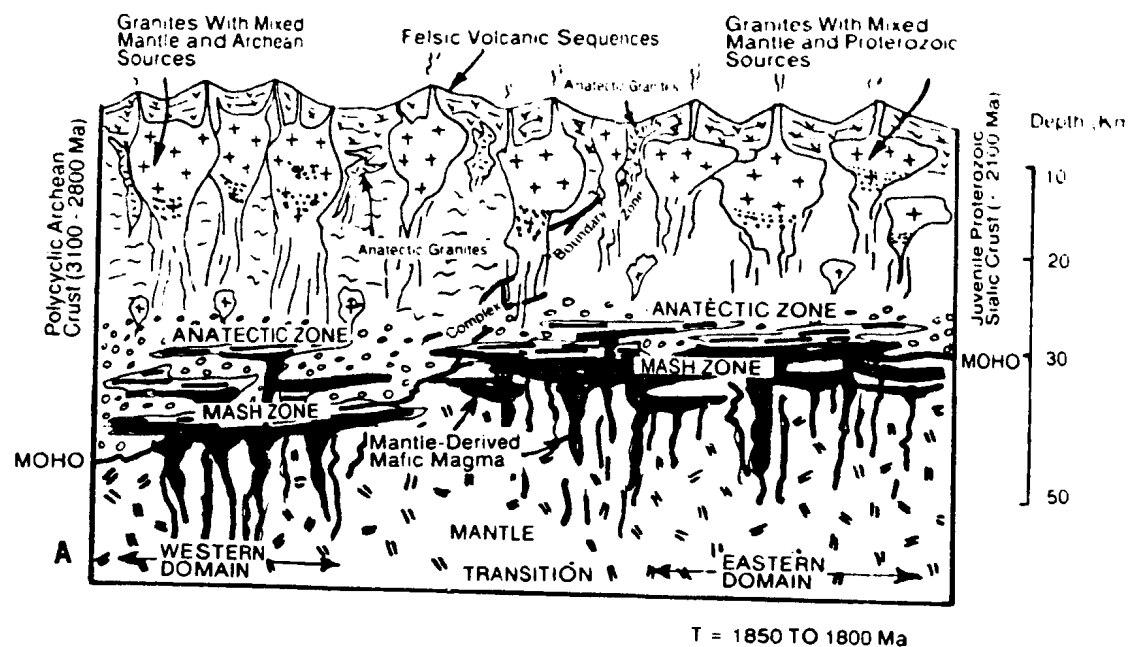
Figure 10.1. A generalized, schematic model for the petrogenesis of Makkovikian magmas. (a) relatively early stages, in which juvenile crust of the eastern zone is extensively thickened. (b) later stages, corresponding to emplacement of the Strawberry Intrusive Suite. Not that depth scales are entirely hypothetical, and approximate. See text for discussion of details.

1988; Whitney, 1988), and are increasingly viewed as a
general mechanism for granite generation in all continental
environments.

The model presented here is influenced by Hildreth and
Moorbath (1988), who suggest that mantle-derived mafic
liquids solidify at or near the crust-mantle boundary,
where their crystallization releases energy. These dense
magmas are "stalled" in the lower crust, where they
assimilate crustal rocks and mix with melts derived from
such sources. The continental crust acts as a density
filter (c.f. Fyfe, 1988), that impedes further ascent of
magmas until compositions evolve to suitably low densities.
Increased ductility and plasticity of partially molten
lower crust also provides a physical barrier to the ascent
of the mafic magmas.

Hildreth and Moorbath (1988) coin the acronym MASH
zone (Melting, Assimilation, Storage and
Homogenization zone) to describe this process.
"Base-level" geochemical and isotopic signatures are
established in the MASH zone as a function of the rate and
characteristics of subcrustal magma flux, and composition
and thickness of overlying crust. Magmas that ascend from
the MASH zone undergo further modification by combined
assimilation - fractional crystallization (DePaolo, 1981a)
at intermediate and upper crustal levels.

The east-west contrast of initial Nd isotopic
compositions observed in Makkovikian rocks illustrates the
influence of the local lower crust on base-level Nd
isotopic signatures developed in the MASH zone. The
base-level elemental signature, however, appears constant
in both domains, indicating that other factors (e.g. bulk
compositions, rate of transfer) were generally similar.

In the eastern domain, the Nd isotopic characteristics
of crustal contributors changed with time. Initially, the

MASH zone was established in slightly older Proterozoic crust, such as the Cape Harrison Metamorphic Suite. During emplacement of the Strawberry Intrusive Suite at ca. 1760 Ma or later, the MASH zone was situated at levels of the crust occupied by juvenile rocks emplaced during previous magmatic episodes, and "crustal" contributions came instead from this material (Figure 10.1b).

This implies thickening of the eastern domain crust via underplating of juvenile material. The greater preservation of volcanic sequences in the western domain, and isotopic evidence for Archean material in western Strawberry Suite magmas, suggests that the western domain was not thickened and uplifted to the same degree, and that its MASH zone remained fixed in Archean lower crust throughout.

Minor syn-tectonic peraluminous granites of the Makkovikian assemblage are interpreted as products of localized anatexis in specific units (e.g. Pitre Lake Granite; Brumwater Granite) or crustal melts that escaped from the upper part of the MASH zone without encountering juvenile material (Figure 10.1a). The Manak Island Granitoid (3.1.6), which is closely similar in composition to the Brumwater Granite, is a possible example of an anatectic granite derived entirely from the juvenile Proterozoic crust of the eastern domain.

Petrogenetic Model -- Some Special Features

It is relevant to consider some consequences of a significantly hotter Earth in early Proterozoic times. Komatiites (ultramafic lavas) and komatiitic basalts of Archean and Early Proterozoic terranes (e.g. Bickle, 1982; Hynes and Francis, 1982) probably reflect extensive mantle melting due to higher thermal gradients, and have high (up to $1600^{\circ}C$) liquidus temperatures. High-Mg magmas of this

general affinity have important implications for the
ultimate products of the MASH process. Sparks (1986)
concludes that they have enormous capacities for thermal
transfer and energy release, as a consequence of high
liquidus temperatures and the large heat of fusion of
olivine, and have great capacities for assimilation and
melting of crustal rocks. Such magmas will evolve initially
via olivine fractionation, which could produce the
Fe-enrichment trends typical of Makkovikian (and other
Proterozoic) granitoid suites.

It is therefore suggested, after Sparks (1986), that
Makkovikian parental magmas were potassic, alkali-rich,
iron-enriched, intermediate magmas generated by interaction
and mixing of (fractionated) high-Mg mafic magma and lower
crustal material. The energy released by olivine
crystallization provided the high temperatures required to
break down hornblende and refractory accessory minerals in
the lower crust. Source materials were probably complex in
detail, as high-Mg mafic magmas can also assimilate or
partially melt mafic compositions, including their own
differentiates (Sparks, 1986). "Zone refining" (e.g.
O'Hara, 1977) processes may thus also contribute to
incompatible element enrichment.

Implications For The Origin Of "A-type" Granites

The Kennedy Mountain, Strawberry and Lanceground
Intrusive Suites are "A-type" or "within-plate" granites
according to most criteria (Chapter ∩). A popular model for
generation of such magmas involves melting of felsic,
granulite-facies, gneisses ("restite") from which anatectic
melts have previously been extracted (Collins et al., 1982;
Whalen et al., 1987). This premise has rarely been
investigated using Nd isotopes.

The "restite" model is incompatible with isotopic data from these rocks, which indicate mixing of mantle and crustal materials, particularly in the western domain (8.2.2). The negligible residence period of any crustal component in the eastern Strawberry Suite also argues against a complex polymetamorphic history. Data from these eastern plutons suggest that some A-type granites are derived entirely from mantle-like sources, although this is probably not a single-stage process (see above).

Nd isotopic data reported here are consistent with an earlier model (Barker et al., 1975), that invoked interaction of mafic magmas and lower crustal rocks. The requirement for prior anatexis in the sources for A-type granites has also been questioned elsewhere (e.g. Anderson, 1983; Kay et al., 1989; Sylvester, 1989). As outlined above, the distinctive characteristics of these rocks may be controlled by the nature of the subcrustal magma flux, rather than by specific sources within the crust.

Two Younger Analogues of The Makkovikian Assemblage

Chapter 9 documents similarities between Makkovikian and Newfoundland granitoid assemblages, but also points out important differences. This section refers briefly to two other possible analogues that have influenced tectonic models presented below. Rapela and Kay (1988) and Kay et al. (1989) draw parallels between Permian to Jurassic felsic magmatism in southern South America and anorogenic magmatism in North America described by Anderson (1983). The South American provinces are dominated by fluorine-rich, "A-type" granites and rhyolites that appear compositionally similar (on the basis of limited geochemical data) to the Makkovikian assemblage. They formed over a 100 to 150 Ma period of magmatism that

followed accretion of juvenile terranes of island-arc or
microcontinental affinity to the margin of Gondwanaland.
Kay et al.(1989) propose that juvenile Paleozoic crust was
underplated and melted by mantle-derived mafic magmas, in a
similar manner to the above model. This area is also
particularly interesting in view of spatial and temporal
relationships to younger Andean magmatism, and assembly of
the Gondwanaland supercontinent (see below).

A Late Proterozoic to Early Paleozoic analogue of the
Makkovik Province may exist in the "Pan-African" mobile
belt of the Arabian Shield (Duyverman et al., 1982; Jackson
et al., 1984; Stoeser, 1986). This is regarded as the prime
example of a Late Proterozoic Wilson cycle, and includes
ophiolitic belts (Pallister et al., 1987). Voluminous,
post-orogenic, granitoid rocks, many of which have "A-type"
affinities, were emplaced over 100 - 150 Ma following
postulated accretion of juvenile volcanoplutonic terranes
interpreted as fossil island arcs (Stoeser and Camp, 1985).
The youngest rocks are fluorine-enriched, variably
peralkaline, mineralized, high-level, granite ring-
complexes of classic "anorogenic" type.

Jackson et al.(1984) and Jackson (1986) proposed that
these suites were generated by fusion of newly accreted
crust, in response to thermal input from the mantle.
Although mantle sources are not specified, it is difficult
to envisage thermal transfer that is unaccompanied by mass
transfer, and consequent geochemical interaction.

10.2 PETROGENESIS OF LABRADORIAN MAGMAS

Summary of Important Characteristics

The Labradorian assemblage comprises a bimodal
association of gabbro-diorite-monzonite-syenite suites

(derived by fractionation of mafic magmas), and assorted siliceous, generally leucocratic granitoid rocks (Chapter 5). These magmas were emplaced, at least in the study area, under passive tectonic conditions. The mafic rocks are of high-potassium, calc-alkaline to shoshonitic affinity; their felsic differentiates have strong incompatible LFS element enrichment as a consequence of protracted fractionation (5.3).

Labradorian granitoid rocks without mafic parental suites have weakly peraluminous compositions, and generally low levels of fluorine, HFS elements and REE, compared to most Makkovikian granitoid rocks. However, they resemble some of the minor, peraluminous, syn-tectonic units of the Makkovikian assemblage.

A comparative analysis of the Labradorian assemblage (Chapter 9) is difficult, probably because these rocks are a small portion of a much wider belt, and may not be fully representative of it. Possible analogues include bimodal, potassic volcanism in distal arc settings (e.g. Brown et al., 1984; Munoz and Stern, 1989) or post-collisional environments (e.g. Sloman, 1989). The former alternative is preferred, mostly on isotopic grounds (8.3.3).

Source Materials and Source Regions

Nd data provide no evidence for depleted mantle sources. Melanocratic, olivine-bearing mafic rocks have ϵ_{Nd}CHUR of ca. +1, well below postulated values (ca. +5 to +6) for a depleted mantle reservoir at 1650 Ma (8.2.2).

Most other Labradorian rocks have similarly neutral isotopic signatures. Excluding the Witchdoctor and Burnt Lake Granites, and a (probably contaminated) gabbro in the extreme west, all have ϵ_{Nd}CHUR of +1 to -2, regardless of composition or geographic location. It is concluded that,

although some Labradorian granites (s.s) could be derived
by anatexis of Makkovikian crust, Labradorian mafic magmas
are mixtures of mantle and crustal materials (8.3.3). It is
suggested that mixing took place in a subcrustal
environment, and not via assimilation and melting of local
lower crust, although some contamination effects are seen
in the Mount Benedict Suite.

By analogy with modern arc magmas (White and Patchett,
1984) and Nd studies of other Proterozoic calc-alkaline
granitoid assemblages (Patchett and Bridgwater, 1984;
Patchett and Kouvo, 1986), it is concluded that crustal
material may have been introduced to the mantle by
subduction of continent-derived sediment (see 8.3.3). The
H_2O-rich nature of the Adlavik Intrusive Suite is also
consistent with this mechanism. Parental magmas to the
mafic-parent suites possibly originated via hydrous melting
of the mantle wedge overlying a subduction zone, initiated
by volatiles and silicic magma derived from the subducted
slab and sediments (Wyllie, 1984; Tatsumi, 1989).

Labradorian granitoid rocks without mafic parental
magmas present a more difficult problem. Their elemental
geochemical features are consistent with derivation by
melting of crustal material under moderate ($650-750^{\circ}C$)
conditions, probably as a consequence of biotite breakdown
(c.f. Whitney, 1988). Low HFS and REE contents indicate
stable zircon and/or sphene in their source regions, which
is also consistent with relatively low temperatures. The
central problem is the identity of a crustal source,
especially in the western domain, where most crustal rocks
probably had negative ϵ_{Nd}CHUR a $\cdot$ 1650 Ma, based on the
observed features of Makkovikian suites. The Witchdoctor
and Burnt Lake Granites could be derived from such a
source, but other Labradorian granitoids require a more
juvenile source, possibly material underplated to the
western domain during Makkovikian magmatism.

Petrogenetic Models

A model for Labradorian magma genesis (Figure 10.2) is, in general terms, a MASH hypothesis (after Hildreth and Moorbath, 1988). The subcrustal magma flux, however, is derived by hydrous melting, has a lower liquidus temperature, lower MgO, and significantly lower ϵ_{Nd}CHUR of ca. +1, compared to the mantle-derived magmas that were involved in Makkovikian magmatism.
The negative displacement of 4 to 5 ϵ_{Nd} units relative to concurrent depleted mantle is identical (in time-adjusted terms) to the shift observed in primitive mafic arc magmas in northern Chile and the Antarctic Peninsula (Pankhurst et al., 1988).

Thermal input from these magmas is limited (compared to the Makkovikian input), crustal melting was less extensive, and took place at lower temperatures. The ability of the MASH process to homogenize and mix mantle and crustal components is also reduced, and there are fewer obstacles to the ascent of variably modified mafic magmas, which fractionate and become contaminated at higher levels. The Mount Benedict Intrusive Suite ascended within the complex boundary zone between eastern and western Makkovikian domains, where it must have encountered some Archean crust at higher levels.

The bimodal Labradorian assemblage is a consequence of suppressed interaction of mantle and crust. In Figure 10.2, Labradorian granites (s.s) are depicted as derivatives of Makkovikian "mixed" granites at intermediate levels, and/or juvenile Makkovikian material that had solidified in the lower crust. It is logical to expect that Archean lower crust of the western domain was extensively diluted by Makkovikian magmatism. In this model the similarity of Nd signatures between Labradorian gabbros and granites (s.s) is coincidental, as they have discrete sources.
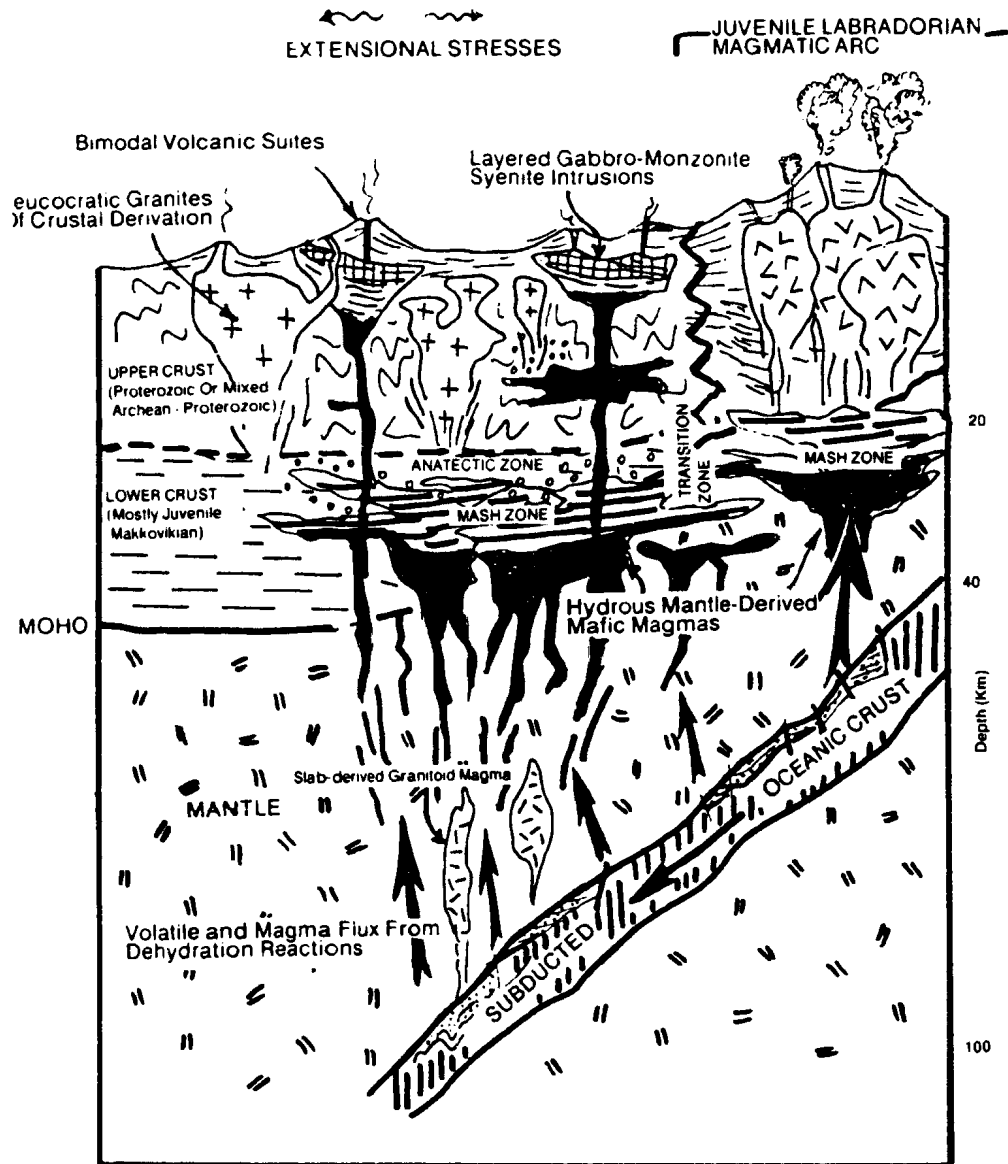
Figure 10.2. A generalized, schematic model for the petrogenesis of Labradorian magmas above a north-dipping subduction zone at ca. 1650 Ma. Note that the main locus of Labradorian activity is inferred to lie south of the study area. Depth scale is approximate.

10.3 PROTEROZOIC CRUSTAL EVOLUTION IN THE MAKKOVIK PROVINCE

Implications For Crustal Growth Models

Makkovikian Events : The period from 2000 to 1700 Ma ago involved widespread orogenic activity and magmatism in the northern hemisphere (e.g. Windley, 1977), and is also important in the southern hemisphere (e.g. Page, 1988; Cordani et al., 1988). Isotopic studies (particularly using Nd) demonstrate that most 2000-1700 Ma crust in North America and Eurasia consists of ca. 80% newly generated, mantle-derived material (Patchett and Arndt, 1986).

The study area is part of this extensive Early Proterozoic tract (e.g. Figure 2.2, p.30), and Nd isotopic data (8.2, 8.3) are broadly consistent with these conclusions, particularly in the eastern domain, where crust formed no earlier than 2100 Ma ago. In the western domain, Archean crust contributed to Proterozoic magmas, but rocks produced <u>entirely</u> from such sources are rare; most contain 50% or more juvenile material, based on conservative mixing calculations (8.3.2). The Makkovik Province was therefore an area of new crust generation in both domains. However, Makkovikian plutonic rocks retain local lower crustal isotopic signatures much more clearly than the Greenlandic and Scandinavian rocks of similar age described by Patchett and Arndt (1986).

Labradorian Events : Nd isotopic data indicate that Labradorian events in the Makkovik Province also added new material to the crust. The isotopic characteristics of these rocks resemble those of the older Scandinavian and

Greenlandic suites examined by Patchett and Bridgwater (1984) and Patchett and Kouvo (1986) in that they consistently contain a small (< 20%) crustal component. However, in the case of Labradorian granites (s.s.), recycling of slightly older, juvenile, Makkovikian crust by anatexis cannot be ruled out. Schärer (1988) found that most Labradorian igneous rocks within the high-grade terranes had neutral or positive ϵ_{Nd}CHUR, and therefore also represent crust generated at or slightly before 1650 Ma.

Stages In Crust Formation : Bickford (1988) reviewed continental crust formation as a three-stage process that occurs sequentially at mid-ocean ridges, above subduction zones, and within accretion-collision zones. In subsequent discussion, these are referred to as <u>Stage 1</u>, <u>Stage 2</u> and <u>Stage 3</u> crustal growth. Bickford (1988) interprets Stage 3 as mostly post-orogenic anatectic melting of material formed in stage 2. However, data presented here indicate that post-orogenic magmatism in the Makkovik Province contributed significantly to new crust generation.

Stage 3 crustal growth is thus visualized here as a consequence of post-orogenic or anorogenic magmatism (the distinction may be semantic at this early stage in Earth history; see later discussion), that results in a vertical reorganization of the crust (after Anderson, 1987; Hoffman, 1989). The mechanism is addition of mantle-derived mafic material at lower levels ("underplating"), coupled with migration of potassic melts or hybrid magmas to form a geochemically evolved upper crust.

Seismic studies indicate that Proterozoic crust is commonly horizontally layered, has a high-velocity lower domain of probable mafic composition (e.g. Drummond and

Collins, 1986), and may have prominent horizontal reflectors in the Middle and Lower Crust (e.g. Pratt et al., 1988). Such features are absent from undisturbed Archean cratons, and are progressively diminished in younger crustal domains. These features are probably a consequence of Stage 3 crustal growth, as described above, which may not have operated widely during the Archean. It is predicted that a proposed seismic transect in the Labrador Sea (Keen et al., 1988) will detect this layered crustal structure under the Makkovik Province (particularly under the eastern domain) but not under the Archean Nain Province.

Labradorian magmatism in the study area is viewed as a distal manifestation of Stage 2 crustal growth processes, occurring via melting of the mantle promoted by dehydration of wet stage 1 crust (ocean floor), with variable addition of continent-derived sediment (White and Patchett, 1984; Bickford, 1988).

Summary : Data from this project support the importance of Early Proterozoic crust formation, as deduced by Patchett and Arndt (1988). It has been suggested that this implies very high rates or large domains of arc magmatism at this time, possibly as much as six times present global arc magma production (Reymer and Schubert, 1986). It may, however, be misleading to assume that all crust is generated by this Stage 2 process, as new crust generation may also take place in post-orogenic environments, and this Stage 3 crust production may have been of greater importance in a hotter Proterozoic Earth (see later discussions).

A Wilson-Cycle Model For The Evolution Of The Makkovik Province

A speculative plate-tectonic model for the evolution of the Makkovik Province is presented below (Figure 10.3). All models of this type are derivative, and this proposal has inherited some features from previous reconstructions by Ryan (1984), who presented alternative collisional and ensialic models. Gower (1985) proposed a tectonic model for Labradorian to Grenvillian events, which covers the period following the final (1650 Ma) step of this proposal. In a general sense, it is also influenced by other models presented for both Precambrian and Phanerozoic orogenic belts (e.g., Stoeser and Camp, 1985; Hoffman, 1988).

The cases for and against Proterozoic lithospheric plate motions have been discussed in counterpoint for many years (e.g. papers in Kroner, 1981, and Medaris et al., 1983), and are beyond the scope of this discussion. The strongest argument in favour of plate tectonics is that it is an <u>observable</u> process resulting from mantle convection and heat loss, facilitated and lubricated by the hydrosphere (Dickinson, 1981; Fyfe, 1988). As Precambrian heat flow cannot have been less than that of today, and the hydrosphere has existed since at least 3800 Ma, it is difficult to imagine an Earth on which processes of this <u>general</u> type did not take place.

Early Stages -- Rifting, sedimentation and Stage 1 Crust Generation

Archean crust of the Nain Province was stabilized by ca. 2800 Ma, and remained stable for a long interval. Mafic dyke swarms were emplaced at ca. 2200 Ma (Grant et al., 1983; Gower and Ryan, 1986). This is ascribed to rifting

and distension of the Archean crust, preceding development
of an oceanic basin to the south-east (Figure 10.3a,b).
There is no <u>direct</u> evidence of this basin, but isotopic
data from the eastern domain indicate a lack of Archean
crust beneath this area.

Supracrustal rocks of the Moran Lake and Lowermost
Aillik Group were subsequently deposited on the margins of
the Archean block; Gower and Ryan (1986) suggested formation
at or before 1900 Ma. There is no direct evidence that the
Lower Aillik Group was <u>deposited</u> on Archean basement, and
it may be part of an oceanic domain, later thrust over the
Archean craton. Mafic volcanic rocks in the upper part of
the Moran Lake Group resemble mid-ocean ridge basalt
(MORB), based on trace element geochemistry (J.North,
pers.comm., 1988).

**Ensimatic Stages -- Subduction and Stage 2 Crust
Generation**

Crustal evolution in the oceanic domain eventually
changed from Stage 1 (ocean-ridge) to Stage 2 (subduction-
zone) crust generation (Figure 10.3c). Mafic volcanic rocks
in the upper portion of the Moran Lake and (possibly) Lower
Aillik Groups may record a back-arc setting, which is not
inconsistent with a MORB-like geochemistry. Nd isotopic
data from the Pitre Lake Granite indicate (albeit
indirectly) that pelitic metasediments of the Lower Aillik
Group had a relatively juvenile source (8.3.1), which could
have been an arc edifice within the area now occupied by
the eastern domain. It is envisaged that one or more arc
systems provided sites for generation of juvenile sialic
crust over subduction zones.

There is evidence of such primitive calc-alkaline
magmatism in other Lower Proterozoic domains. The

Svecokarelian belt of Finland includes 1930 - 1860 Ma old gabbro, tonalite and trondhjemite suites that resemble younger ensimatic and continental arc assemblages (Nurmi and Haapala, 1986). In Sweden, volcanic belts of 1900 - 1850 Ma age are both geochemically and metallogenically similar to modern island arcs, and were intruded by tonalitic granitoid rocks (Wilson et al., 1985; Lagerblad et al., 1987). Nd Isotopic studies suggest that these areas all represent juvenile, Proterozoic crust (Wilson et al., 1985; Patchett and Kouvo, 1986). The southern part of the Ketilidian Belt (migmatite zones of Allaart, 1976) may also represent such material (see later discussions).

Direct evidence of oceanic crust has always been a central problem in the interpretation of Proterozoic mobile belts. Scott et al. (1989) have, however, described a convincing 2000 Ma old ophiolitic assemblage from the Cape Smith Fold Belt of northern Quebec. To date, however, no such assemblages have been reported from the Ketilidian or Svecokarelian belts.

Early Ensialic Stages -- Accretion Of Juvenile Terranes and Initiation of Stage 3 Crust Generation

Subduction of oceanic crust leads inexorably to accretion of exotic terranes to the active margin, as postulated for modern orogenic systems (e.g. Coney et al., 1980). This accretion probably took place ca. 1850 Ma or earlier (Figure 10.3d), and is recorded by subhorizontal deformation and high-grade metamorphism of the Lower Aillik Group, and generation of minor anatectic granites from both juvenile and Archean crustal blocks. The Cape Harrison Metamorphic Suite is the largest preserved fragment of an accreted, pre-Makkovikian, juvenile terrane. Gneissic rocks

EARLY STAGES (ca. 2200 Ma)

A
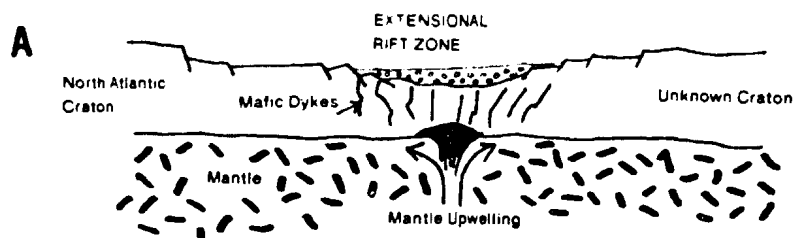
STAGE TWO (ca. 2100 - 2000 Ma)

B
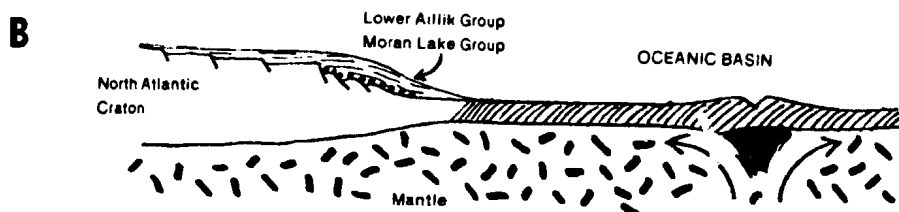
STAGE 3 : ENSIMATIC STAGES (ca. 2000 - 1900 Ma)

C
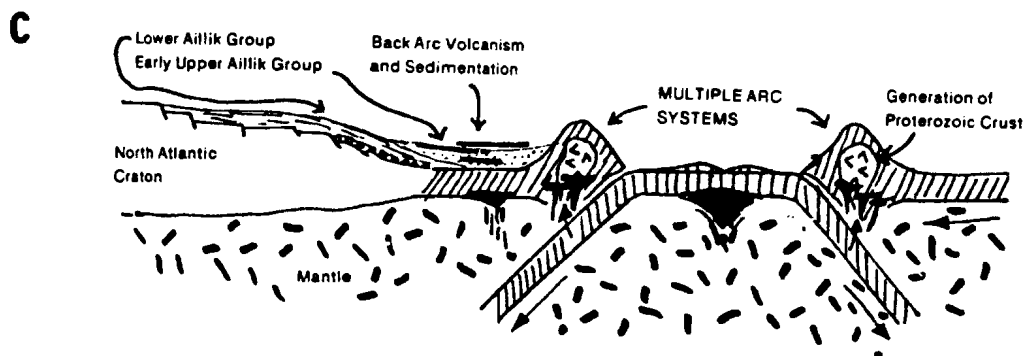
Figure 10.3. A proposed plate-tectonic framework for Makkovikian and Labradorian events in the study area. For a continuation of possible events after 1650 Ma, see Gower (1985). See text for discussion of subfigures (a) to (f).

STAGE 4 : EARLY ENSIALIC STAGE (ca. 1850 Ma)
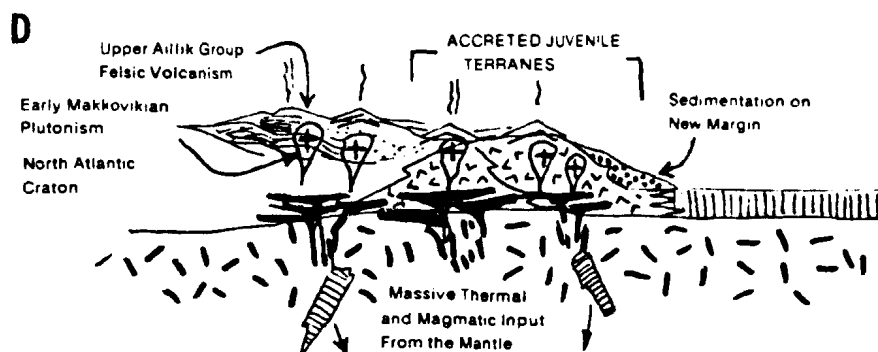
STAGE 5 : LATE ENSIALIC STAGE (ca. 1800 - 1700 Ma)
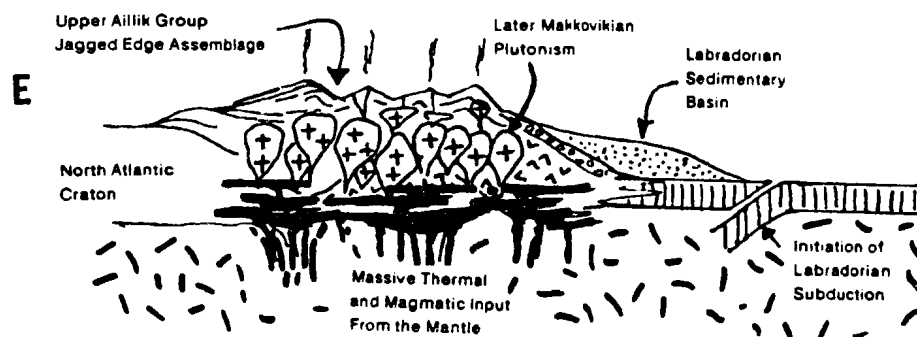
STAGE 6 : LABRADORIAN CYCLE (ca. 1650 - 1600 Ma)
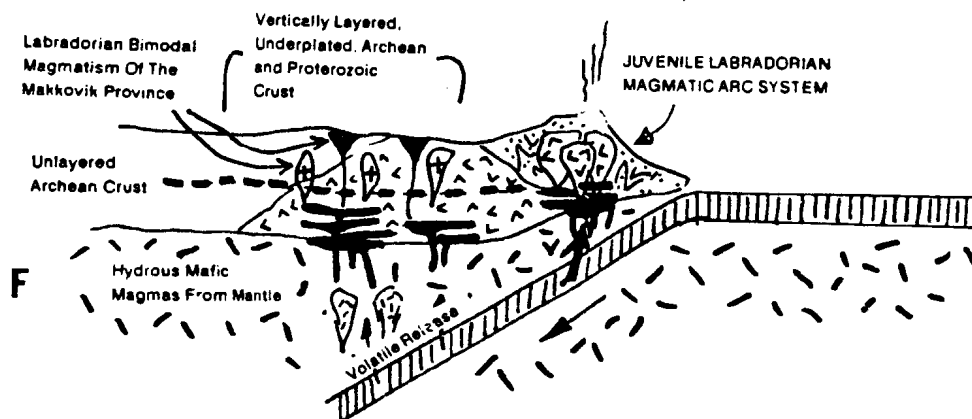
Figure 10.3 (continued). The heavy dashed line in (f) indicates the vertical layering of crust affected by Proterozoic events, as opposed to undisturbed Archean cratonic areas.

east of the study area in Labrador (Owen et al., 1986) are
also possible candidates. Tonalitic and trondhjemitic rocks
of the Island Harbour Bay Intrusive Suite (which are highly
atypical of Makkovikian magmatism) may record a brief
period of subduction beneath the Archean continental
margin.

During accretion, crust generated by Stage 2 processes
was tectonically thickened. An insulating blanket was
formed over hot mantle, and the build-up of heat induced
mantle melting. Early Stage 3 crust generation commenced
shortly after accretion, via emplacement of mafic magmas
into the base of both Archean and juvenile domains. The
consequences of this activity are discussed above (10.1).
Final tectonic movements were partly contemporaneous with
this early Makkovikian magmatism, and some intrusions are
deformed by virtue of their age and/or location. Initiation
of Upper Aillik Group felsic volcanism dates from this
period; the mixed assemblage of the earliest Upper Aillik
Group may record pa.t of the back-arc setting indicated in
Figure 10.3c.

Late Ensialic Stages -- Episodic Post-Tectonic Magmatism and Stage 3 Crust Formation

This stage corresponds to the main Makkovikian plutonic
as.;emblage of ca. 1800 - 1760 Ma (and possibly younger)
age. This activity continued vertical reorganization of the
crust, as discussed previously (10.1). Thickening via
underplating was greatest in the thinner eastern domain
crt;t, which was also probably hotter, and richer in
volatiles than granulitic Archean lower crust in the west
(Figure 10.3e).

By the time the Strawberry Intrusive Suite was
emplaced, both domains had similar thicknesses and

elemental compositions, accounting for the geochemical coherence of these plutons across the margin of the Archean craton. Volcanic rocks of the Jagged Edge assemblage may record volcanism associated with the Strawberry Suite, as they have a similarly primitive initial Nd composition. However, they could also be of Labradorian age (see 7.3, 8.3 for discussions).

Extensive reprocessing of the juvenile, recently-accreted crust is implicit in the stage 3 crust formation envisaged during this period. Scattered, enigmatic outcrops of layered or banded material encountered during mapping of plutonic units may be enclaves or screens of older juvenile crust, in addition to the larger remnant at Cape Harrison.

Labradorian Stages -- Initiation of a New Active Margin South Of The Makkovik Province

The waning stages of the Makkovikian episode were followed by, or were contemporaneous with, the initiation of Labradorian events. It is suggested that northward-directed subduction began under this margin after cessation of Makkovikian plutonism, and was well underway by 1650 Ma. The study area was by now distal to the active zone, and magmatic and deformational effects were minor. Bimodal Labradorian magmatism, corresponding to the model presented above (10.2), was the result.

Gower (1985) proposed that a long-lived convergent plate boundary developed during the Labradorian event, and offers some interesting speculations on the nature of the subsequent Grenvill.an Orogeny, a subject del.berately avoided here.

These suggestions do not imply that all igneous rocks in the Labrador Orogen are related to this northward-directed subduction, as it is likely that Stage 3 crust formation subsequently took place in this area also.

Relationship of Makkovikian and Labradorian Magmatic Provinces Within The TLGB

Makkovikian and Labradorian events are viewed as phases in long-term crustal evolution along the margin of a developing supercontinent. Makkovikian magmatism was associated with the accretion of Proterozoic terranes to an Archean nucleus, and (in a broader sense) to the assembly of this supercontinent (Hoffman, 1988). Labradorian magmatism reflects subsequent subduction along its southern boundary. The TLGB in the Makkovik Province is thus a composite belt, but dominated by Makkovikian rocks.

A possible reconstruction of the situation at ca. 1650 Ma is illustrated in Figure 10.4a. Makkovikian and Labradorian magmatic belts diverge, and continue into southern Greenland and southern Labrador respectively. The Granitoid Zone of the Ketilidian Mobile Belt (Allaart, 1976) contains a similar assemblage of intrusive rocks, but may contain more remnants of Stage 2 crust. The folded and flat-lying migmatite zones in the south of the Ketilidian belt (Allaart, 1976) may represent the accreted juvenile block (*Ketilidia* ?). To the west, the Makkovikian belt may join with the ca. 1800 Ma old Ungava or DePas batholith (Wardle et al., in press) in the Churchill Province. Alternatively, it may be continuous with the Penokean belt of the midcontinent region, as implied by Thomas et al. (1985).

Either alternative implies that central and western portions of the TLGB are also composite Makkovikian-Labradorian magmatic provinces. Makkovikian U-Pb ages have not yet been reported from this area (Thomas et al., 1986), but Makkovikian rocks would be very hard to recognize using field criteria. Unless these areas are underlain by Archean material, Makkovikian and Labradorian components of the TLGB would probably also have similar ϵ_{Nd} signatures.
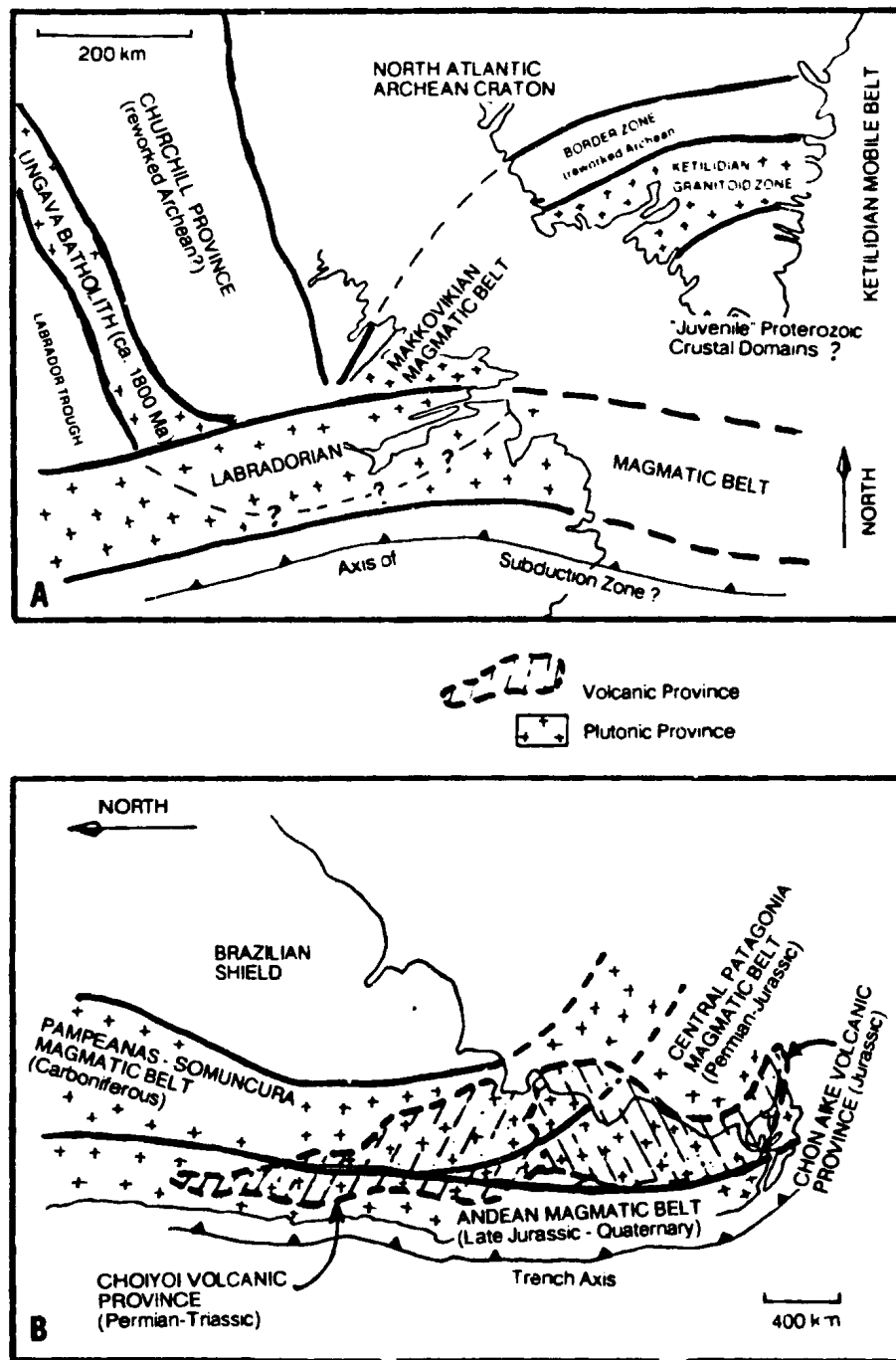
Figure 10.4. (a) A possible paleogeographic configuration of Makkovikian, Ketilidian and Labradorian magmatic provinces at ca. 1650 Ma. (b) Paleozoic, Mesozoic and Cenozoic magmatic belts developed at the margin of Gondwanaland in southern South America (after Ramos, 1988; Rapela and Kay, 1988). This area is proposed as a possible analogue to sequential events in the study area. Note that there is a large difference in scale between (a) and (b).

A Younger Analogue -- The Margin of Gondwanaland in
Southern South America

   The southern South American margin of Gondwanaland
(Ramos et al., 1986; Ramos, 1988; Rapela and Kay, 1988; Kay
et al., 1989) may provide a general analogue to the above
model. A simplified map of its major tectonic elements is
shown in Figure 10.4b. There is a very large difference in
scale between Figures 10.4a and 10.4b, and no exact
geographic correspondences are implied. The comparison
simply illustrates similarly protracted magmatic evolution
on the margin of a developing supercontinent.

   The earliest rocks in this area consist of Middle to
Late Paleozoic supracrustal rocks and syntectonic granitoid
rocks. Ramos et al. (1986) view these as continental margin
and oceanic terranes that were assembled into Gondwanaland
at the end of the Devonian, recording final stages in
assembly of the supercontinent. Their accretion was
followed by emplacement of the Pampeanas - Somuncura
(Carboniferous to Permian) and Central Patagonia
(Triassic-Jurassic) granitoid batholiths (Rapela and Kay,
1988). Both are siliceous and potassic granitoid belts,
rather than expanded calc-alkaline suites. In Patagonia,
their trends diverge from the younger Andean belt. However,
in the north, they are parallel to it, and rocks of similar
affinity occur within the Andean magmatic belt. The
Gondwanaland batholiths are associated with the
aforementioned Choyoi (Permian) and Chon Aike (Early
Jurassic) silicic volcanic provinces, for which
petrogenetic models (Kay et al., 1989) are similar to those
presented above for the Makkovikian assemblage (10.1).

   These final Gondwanaland events were soon followed by
initiation of a new active margin, represented by the Late
Jurassic to Quaternary magmatism of the Andes, built on a

Paleozoic substrate in the north and upon juvenile "arc"
crust in the south (Hildreth and Moorbath, 1988). Where
Gondwanaland and Andean magmatic provinces are
superimposed, magmatism was episodic from Devonian to
Cenozoic, a 250 - 300 Ma period that easily encompasses
Makkovikian and Labradorian events in Labrador. It is
suggested here, partly after Kay et al.(1989), that
assembly of Gondwanaland is analogous to the creation of
Proto- Laurentia and establishment of a mobile zone along
its southern margin, as described by Hoffman (1988).

In this context, it is interesting to speculate on
eventual destruction of the Pacific Ocean. When this event
finally transpires, will the resultant collisional orogeny
bear the same temporal relationship to Gondwanaland and
Andean cycles as the Grenvillian orogeny bears to
Makkovikian and Labradorian events ?

The Makkovik Province as Part of a Chelogenic Cycle

Sutton (1963) proposed the term "chelogenic cycle" to
explain the episodic nature of global orogenies in terms of
the aggregation and disperal of large continents. A recent
revival of such ideas is exemplified by two brief papers
from the contrasting disciplines of theoretical geophysics
and regional geology (Gurnis, 1988; Hoffman, 1989).

Gurnis (1988) modelled "feedback" between lithospheric
plate motions and mantle convection patterns. He suggested
that continents will inevitably aggregate over downwellings
(cool areas) in the mantle. Once aggregated, they become
stationary or slow-moving, and insulate large areas of the
mantle. Rising temperatures in the mantle create a thermal
upwelling (i.e., a series of plumes) that eventually rifts
the continent and disperses the fragments towards colder
mantle areas (downwellings).

Hoffman (1989) applied these (and other) model results in an elegant discussion of the North American Precambrian Shield, couched in an interesting four-movement musical analogy (referred to by the editors of *Geology* as a "Superswell Symphony"). The model proposes that a Proterozoic supercontinent (c.f. Piper, 1983) aggregated over a mantle downwelling between 1900 and 1700 Ma ago, and that its assembly is defined by worldwide orogeny and crust generation at this time, followed by further crust generation along its margins. These events correspond to Makkovikian and Labradorian stages described above.

Insulation of the mantle by Archean cratons and large tracts of juvenile crust induced the long-lived "anorogenic" magmatism of the Middle Proterozoic via episodic thermal and magmatic input from the mantle. A similar model for anorogenic magmatism was previously advocated by Anderson (1987).

The model proposed here fits into these events well, and with the proposals of Kay et al.(1989), who also applied the models of Gurnis (1988) to the final assembly of Gondwanaland. Significantly, the Pan-African belt of Arabia, referred to above as another possible analogue to Makkovikian events, is also part of a period of continental assembly (e.g. Bowden and Kinnaird, 1987).

Hoffman (1989) suggested qualitatively that the first supercontinental assembly would experience the most intense "anorogenic" magmatism as a consequence of greater mantle heat flow during the Early Proterozoic. A hotter mantle also has implications for the relationships between "post-orogenic" and "anorogenic" magma ism, and for crustal growth mechanisms.

Proterozoic Magmatism and Crustal Evolution : Reprise

If, as suggested by this study, Stage 3 (post-orogenic)
crustal growth is an important process, it must have played
a greater role in a hotter Earth, where the build-up of
heat in subcontinental mantle would be greater and more
rapid. Gurnis (1988) proposed a ca. 300 Ma interval between
assembly and rifting of supercontinents, based on
present-day Earth parameters. A hotter mantle, and greater
radiogenic heat production, would shorten this interval. In
such a situation, Stage 2 crust accreted to a aggregating
continent would encounter the effects of overheated mantle
very soon after its arrival. Stage 3 crustal growth would
occur widely in post-orogenic settings, and would be more
intense and widespread than in younger belts. It may
therefore have contributed to the apparent high growth
rates of some Early Proterozoic crustal provinces noted by
Reymer and Schubert (1986). These authors also proposed
unusually rapid growth for the Pan-African of Arabia, which
may also record a period of supercontinent assembly.

Diminishing importance of Stage 3 crustal growth
through geological time also accounts for differences
between Proterozoic and Phanerozoic crustal structure noted
by Drummond and Collins (1986).

A corollary of this proposal is that the distinction
between "post-orogenic" and "anorogenic" magmatism becomes
progressively blurred as we reach back in geological time.
In Phanerozoic and modern environments, "anorogenic"
magmatism is seen as a separate, discrete environment
because the time lag between continental assembly and
mantle upwelling is long ($\geq$ 300 Ma). In the Early
Proterozoic, post-orogenic and anorogenic magmatism
probably formed a continuum, linked by a common process,

i.e. a large thermal and magmatic input from the mantle. In a younger, cooler Earth, this is present only in more restricted environments such as hot-spots, and requires a longer preceding period of insulation to develop.

If the relative importance of Stage 2 (subduction zone) and Stage 3 (post-orogenic to anorogenic) crustal growth has changed through time, preservation of juvenile calc-alkaline material should be less common in older terranes, as a consequence of greater reprocessing, and of greater uplift and erosion caused by underplating. Testing such a prediction is very difficult, but a scarcity of such material is the most common objection cited against plate tectonic models (e.g. Kroner, 1983; Glikson, 1983). This scarcity may be a real feature, but does not imply absence of Stage 2 crustal growth processes, but rather greater intensity of Stage 3 processes, particularly during periods of continental aggregation.

It should be stressed also that preservation of juvenile volcanic-arc like assemblages is rare in orogenic belts of all ages, excluding incomplete cycles such as those of the circum-Pacific region. In the Appalachians, for example, pre-Taconic tonalitic and trondhjemitic granitoid rocks of probable arc affinity represent only a few percent of exposed granitoid rocks, most of which are post-orogenic (Hayes et al., 1987; Williams et al., 1989). The dominant granitoid intrusive rocks in orogenic belts of all ages are invariably the post-orogenic products of Stage 3 crustal growth processes.

Th's study has shown that Lower Proterozoic magmatism in the Makkovik Province is indeed geochemically distinct from younger analogues (Chapter 9). However, it is felt that such differences do not necessarily require unique, non-uniformitarian models, but are explicable via plate tectonics, with some modifications to account for declining heat flow through geological time.

10.4 FUTURE PATHS

Regional projects such as this inevitably pose more questions than they are able to resolve. Some areas of further investigation and possible subprojects are listed in point form here.

Isotope Geochemistry : Multiple isotopic systems are required in an ideal study of crust generation. Sr data from mineral separates, and Pb isotope data, could both constrain mantle and crustal contributions more precisely, by requiring a more unique mixing solution. Oxygen isotope studies could discriminate upper, lower and supra-crustal sources.

The Kaipokok Bay fold belt offers a chance to examine the behaviour of isotopic systems during anatexis of different protoliths. The very unusual Nd signature of the Pitre Lake granite suggests that results could have important implications.

Geochronology : Geochronological problems are as numerous as units. Recent revision of the age of the Strawberry Intrusive Suite to ca. 1720 Ma (Krogh et al., in prep, see footnote on p.113) has extended the duration of post-tectonic Makkovikian plutonism. The extent of this younger Makkovikian magmatism requires evaluation. Units that require dating include the Kennedy Mountain Suite (which may delimit Makkovikian deformation), the Lanceground Intrusive Suite (is this the same age as the Numok Suite, or is it similar in age to the Strawberry Suite ?), and the volcanic rocks of the Jagged Edge assemblage (are these equivalent to the Strawberry Suite, or Labradorian ?). Dating of the Cape Harrison Metamorphic Suite is also crucial.

Petrological and Geochemical Studies : The Adlavik
and Mount Benedict Intrusive Suites are fascinating
intrusions that record the protracted fractionation of
potassic, possibly shoshonitic mafic magmas. Trace element
models presented here (5.3) are only a first approximation
to the problem and require constraining by major element
mass-balance solutions, and further exploration of coupled
assimilation-fractional crystallization models (DePaolo,
1981a). The greatest problem with the mafic intrusions is
their horrific complexity; they require devoted and
time-consuming detailed mapping to delineate their many
individual magma batches. The scale of this study has
precluded such rigorous mapping. Amongst granitoid suites,
the Strawberry Intrusive Suite and similar A-type suites
are of most interest to the author, particularly in terms
of their implications for the petrogenesis of such rocks.
The Cape Harrison Metamorphic Suite requires further work,
as it has an important role in models. Description as
tonalitic to granodiorite is presently based mostly on
field and petrographic data (Gower, 1981), .

Mineral Chemistry Studies : This aspect is largely
untouched here (a few imprecise probe analyses were carried
out purely for identification purposes). Recent studies by
Ague and Brimhall (1988a,b) use mafic and accessory mineral
geochemistry to study source characteristics and conditions
of emplacement in the Sierra Nevada Batholith. These have
potential for application in the TLGB, particularly in
combination with isotopic data, and with reference to
contrasts between eastern and western domains.

Spectral Analysis Of Granitoid Batholiths : The largely univariate treatment of Chapter 9 can be expanded with multivariate techniques, and some work of this type has already been done using factor analysis (e.g. Kerr, 1988). It is increasingly apparent that discriminant diagrams do not provide adequate characterization of tectonic environments, and it is important that emphasis also be placed on extensive parameters, and compositional structure and evolution. This can only be addressed via structured sampling programs of the type employed here, and by greater international availability of representative data. It is felt that this general approach has potential, and it is hoped that these TLGB data, although far from fully understood, will eventually contribute to better characterization of granitoid magmatism via geochemistry. Data will be made available via the ARTEMISE data bank and via the Newfoundland Department of Mines. Much effort is addressed in granite petrology towards categorization of unique magma types, as exemplified by the ever-popular I-, S-, A- and M- type terminology. In the words of Hildreth (1987), "......*such cryptonyms encourage pigeonholing rather than the thoughtful consideration needed to understand multicomponent compositional spectra....*". I hope, as does Fyfe (1988), that the origins of granites will no longer be subjects of debate in 2089 (see quotations after title page), but I wonder if such statements might be overly optimistic in view of the inherent complexity of the topic !

REFERENCES CITED

ABBEY, S. , 1979.
Studies in "standard samples" for use in the general analysis of silicate rocks and minerals. Part 6 : 1979 edition of "usable" values. Geological Survey of Canada, Paper 80-14, 30 pp.

ABBEY, S. , 1983.
Studies in "standard samples" of silicate rocks and minerals. Geological Survey of Canada, Paper 83-14, 114 pp.

AGUE, J.J. and BRIMHALL, G.H. , 1988a.
Regional variations in bulk chemistry, mineralogy, and the compositions of mafic and accessory minerals in the batholiths of California. Bulletin of the Geological Society of America, v.100, p.891-911.

AGUE, J.J. and BRIMHALL, G.H. , 1988b.
Magmatic arc asymmetry and distribution of anomalous plutonic belts in the batholiths of California: Effects of assimilation, crustal thickness, and depth of crystallization. Bulletin of the Geological Society of America, v.100, p.912-917.

ALLAART, J.H. , 1976.
Ketilidian mobile belt of West Greenland. In: Escher,A. and Watt,W.S., (eds.). Geology of Greenland. Gronlands Geologiske Undersogelse, Copenhagen, p.120-152

ANDERSON, J.L. , 1983.
Proterozoic anorogenic granite plutonism of North America. In: Medaris,L.G., et al. (eds.). Proterozoic Geology. Geological Society of America, Memoir 161, p.133-154.

ANDERSON, J.L. , 1987.
The nature and origin of the A-type magmatism in the Proterozoic IGCP Project 217 (Proterozoic Geochemistry), Lund, Sweden, June 1987. Program with abstracts, p.1.

ARCHIBALD, D. and FARRAR, E. , 1979.
40Ar/39Ar mineral ages from the Walker - Benedict granodiorite, Central Mineral Belt, Labrador. Newfoundland Dept. Mines and Energy, Mineral Development Division, unpublished report, 12 pp.

ARNDT, N.T. and GOLDSTEIN, S.L. , 1987.
Use and abuse of crust-formation ages. Geology, v.15, p.893-895.

ARTH, J.G. , 1976.
Behaviour of trace elements during magmatic processes - A summary of theoretical models and their applications. Journal of Research of the U.S. Geological Survey, v.4, p.41-47.

ASHWAL, L.D., WOODEN, J.L. and EMSLIE, R.F. , 1986.
Sr, Nd and Pb isotopes in Proterozoic intrusives astride the Grenville Front in Labrador: Implications for crustal contamination and basement mapping. Geochimica et Cosmochimica Acta, v.50, p.2571-2585.

ATHERTON, M.P. , 1984.
The coastal batholith of Peru. In : Harmon, R.S. and Barriero, B.A.(eds.) Andean Magmatism. Shiva Publishing, Nantwich, U.K., p.168-180.

BAILEY, D.G. , 1979.
Geology of the Walker Lake-Maclean Lake area, Central Mineral Belt, Labrador. Newfoundland Dept. Mines and Energy, Mineral Development Division, Report 79-3. 36 pp.

BAILEY, D.G., FLANAGAN, M.J. and LALONDE, A. , 1979.
Geology of the eastern Central Mineral Belt, Labrador. Newfoundland
Dept. Mines and Energy, Mineral Development Division, Report 79-1,
p. 103-108.

BAILEY, J.C. , 1977.
Fluorine in granitic rocks and melts: A review. Chemical Geology,
v.19, p.1-42.

BAIRD, A.K. and MIESCH, A.T. , 1984.
Batholithic rocks of southern California - A model for the
petrochemical nature of their source materials. United States
Geological Survey, Professional Paper 1284, 42 pp.

BAIRD, A.K., BAIRD, K.W. and WELDAY, E.E. , 1974.
Chemical trends across Cretaceous batholithic rocks of southern
California. Geology, v.2, p.493-496.

BARKER, F., WONES, D.R., SHARP, W.N. and DESBOROUGH, G.A. , 1975.
The Pikes Peak Batholith, Colorado Front Range, and a model for the
origin of the gabbro-anorthosite-syenite-potassic granite suite.
Precambrian Research, v.2, p.97-160.

BARTH, T. , 1955.
Presentation of rock analyses. Journal of Geology, v.63, p.348-363.

BARUA, M.C. , 1969.
Geology of uranium-molybdenum bearing rocks of the Aillik-Makkovik
Bay areas, Labrador. Unpublished M.Sc Thesis, Queen's University,
Kingston, Ontario, 76 pp.

BATEMAN, P.C. , 1988.
Stratigraphic classification and nomenclature of igneous and
metamorphic rock bodies - Discussion. Bulletin of the Geological
Society of America, v.100, p.995-997.

BEAVAN, A.P. , 1958.
The Labrador uranium area. Proceedings of the Geological Association
of Canada, v.10, p.137-145.

BICKFORD, M.E. , 1988.
The formation of continental crust: Part 1. A review of some
principles; Part 2. An application to the Proterozoic evolution of
southern North America. Bulletin of the Geological Society of
America, v.100, p.1375-1391.

BICKLE, M.J. , 1982.
The magnesium contents of komatiitic liquids. In: Arndt, N.T. and
Nisbet, E.G.(eds.). Komatiites, p.479-494. Allen and Unwin.

BOWDEN, P. and KINNAIRD, J. , 1987.
Proterozoic orogenies, magmatism and related metallogeny. Geological
Journal, v.22, p.81-85. (thematic issue on African geology).

BOWDEN, P., BATCHELOR, R.A., CHAPPEL, B.W., DIDIER, J. and LAMEYRE, J.,
1984.
Petrological, geochemical and source criteria for the classification
of granitic rocks: A discussion. Physics of Earth and Planetary
Interiors, v.35, p.1-11.

BRIDGWATER, D., ESCHER, A., JACKSON, G.D., TAYLOR, F.C., and
WINDLEY, B.F. , 1973.
Development of the Precambrian shield in West Greenland, Labrador
and Baffin Island. In: Arctic Geology. American Association of
Petroleum Geologists, Memoir 19, p.99-116.

BROOKS, C. , 1979.
    Report on the geochronology of Labrador (Subproject 1.09).
    Newfoundland Dept. Mines and Energy, Mineral Development Division,
    unpublished report.

BROOKS, C. , 1982.
    Third report on the geochronology of Labrador. Newfoundland Dept.
    Mines and Energy, Mineral Development Division, unpublished report.

BROOKS, C. , 1983.
    Fourth report on the geochronology of Labrador. Newfoundland Dept.
    Mines and Energy, Mineral Development Division, unpublished report.

BROOKS, C., HART, S.R. and WENDT, I. , 1972.
    Realistic use of two-error regression treatments as applied to Rb-Sr
    data. Reviews of Geophysics and Space Physics, v.10, p.551-577.

BROWN, G.C. , 1981.
    Time and space in granitoid plutonism. Philosophical Transactions of
    the Royal Society of London, v.A301, p.321-336.

BROWN, G.C., THORPE, R.S., and WEBB, P.C. , 1984.
    The geochemical characteristics of granitoids in contrasting arcs,
    and comments on magma sources. Journal of the Geological Society of
    London, v.141, p.413-426.

BROWN, M. , 1987.
    The granites of the coastal cordillera, northern Atacama region,
    Chile. Terra Cognita, v.7, p.277.

BROWN, M. , 1988.
    Geochemistry of the granitic complexes, 26-27 degrees south,
    northern Chile. Actas de Congreso Geologico Chileno, v.5, Tomo 3,
    p.153-166. Departamento de Geologia y Geofisica, Universidad de
    Chile.

CHAPPELL, B.W. and WHITE, A.J.R , 1974.
    Two contrasting granite types. Pacific Geology, v.8, p.173-174.

CHAPPELL, B.W and STEPHENS, W.E. , 1988.
    Origin of infracrustal (I-type) granite magmas. Transactions of the
    Royal Society of Edinburgh, Earth Sciences, v.79, p.71-86.

CHAPPELL, B.W., WHITE, A.J.R, and HINE, R. , 1988.
    Granite provinces and basement terranes in the Lachlan Fold Belt,
    southeastern Australia. Australian Journal of Earth Sciences, v.35,
    p.505-521.

CHAUVEL, C., ARNDT, N.T., KIELINZCUK, S. and THOM, A. , 1987.
    Formation of Canadian 1.9 Ga old continental crust. 1: Nd isotopic
    data. Canadian Journal of Earth Sciences, v.24, p.396-406.

CHRISTIE A.M. , ROSCOE, S.M. and F''RIG, W.F. , 1953.
    Cent. al Labrador Coast, Newfoui_.and. (Descriptive Notes).
    Geolcｊical Survey of Canada, Paper 53-14, 3 pp.

CLARK, A.M.S. , 1970.
    A structural re-interpretation of the Aillik Series, Labrador.
    Unpublished M.Sc. thesis, Memorial University, St.John's,
    Newfoundland, 76 pp.

CLARK, A.M.S. , 1973.
    A re-interpretation of the stratigraphy and structure of the Aillik
    Group, Makkovik, Labrador. Unpublished Ph.D. thesis, Memorial
    University, St. John's, Newfoundland, 346 pp.

CLARK, A.M.S. , 1979.
Proterozoic deformation and igneous intrusion in part of the
Makkovik subprovince. Precambrian Research, v.10, p. 95-114.

CLEMENS, J.D., HOLLOWAY, J.R. and WHITE, A.J.R. , 1986.
Origin of an A-type granite: experimental constraints. American
Mineralogist, v.71, p.317-324.

COBBING, E.J., PITCHER, W.S. and TAYLOR, W.P. , 1977.
Segments and superunits in the Coastal Batholith of Peru. Journal of
Geology, v.85, p.625-631.

COIRA, B., DAVIDSON, J., MPOZODIS, C. and RAMOS, V.A. , 1982.
Tectonic and magmatic evolution of the Andes of northern Argentina
and Chile. Earth Science Reviews, v.18, p.303-333.

COLLERSON, K.D. , 1982.
Geochemistry and Rb-Sr geochronology of associated Proterozoic
peralkaline and subalkaline granites from Labrador. Contributions to
Mineralogy and Petrology, v.81, p.126-147.

COLLERSON, K.D. and BRIDGWATER, D. , 1979.
Metamorphic development of Early Archean tonalitic and trondhjemitic
gneisses, Saglek area, Labrador. In Barker, F. (ed.). Trondhjemites,
Dacites and Related Rocks. Elsevier, Amsterdam, p.205-273.

COLLINS, W.J., BEAMS, S.D., and WHITE, A.J.R , 1982.
Nature and origin of A-type granites with particular reference to
Southeastern Australia. Contributions to Mineralogy and Petrology,
v.80, p.189-200.

COLMAN-SADD, S.P. , 1982.
Two-stage continental collision and plate driving forces.
Tectonophysics, v.90, p.263-282.

CONDIE, K.C. , 1981a.
Precambrian rocks of southwestern United States and adjacent areas
of Mexico. Scale 1:1,000,000. New Mexico Bureau of Mines and Mineral
Resources, Map 13.

CONDIE, K.C. , 1981b.
Archean Greenstone Belts. Elsevier, Amsterdam, 434 pp.

CONDIE, K.C. , 1982.
Plate tectonics model for Proterozoic continental accretion in the
Southwestern United States. Geology, v.10, p.37-42.

CONEY, P.J., JONES, D.L., MONGER, J.W.H. , 1980.
Cordilleran suspect terranes. Nature, v.288, p.329-333.

CORDANI, U.G., TEIXEIRA, W., TASSINARI, C.G., KAWASHITA, K and
SATO, K. , 1988.
The growth of the Brazilian Shield. Episodes, v.11, p.163-167.

COX, K.G., BELL, J.D. and PANKHURST, R.J. , 1979.
The Interpretation of Igneous Rocks. Allen & Unwin, London, 450 pp.

DALY, R.A. , 1902.
The geology of the northeast coast of Labrador. Bulletin of the
Museum of Comparative Zoology, Harvard University, v.38, p.205-269.

DEBON, F. and LEFORT, P. , 1982.
A chemical mineralogical classification of common plutonic rocks and
associations. Transactions of the Royal Society of Edinburgh, Earth
Science, v.73, p.135-149.

DEBON, F., LEPORT, P., SHEPPARD, S.M. and SONET, J. , 1986.
    The four plutonic belts of the Transhimalaya-Himalaya: A chemical,
    mineralogical, isotopic and chronological synthesis along a
    Tibet-Nepal section. Journal of Petrology, v.27, p.219-250.

DEBON, F., AFZALI, H., LEFORT, P. and SONET, J. , 1987a.
    Major intrusive stages in Afghanistan: Typology, age and geodynamic
    setting. Geologische Rundschau, v.76, p.245-264.

DEBON, F., AFZALI, H., LEFORT, P., SONET, J. and ZIMMERMAN, J.L. ,
1987b.
    Plutonic rocks and associations in Afghanistan: Typology, age and
    geodynamic setting. CNRS-CRPG, Nancy, France. Memoires Sciences de
    la Terre, Numero 49, 132 pp.

DEBON, F., LEFORT, P., DAUTEL, D., SONET, J and ZIMMERMAN, J.L. ,
1987c.
    Granites of western Karakorum and northern Kohistan (Pakistan): A
    composite Mid-Cretaceous to Upper Cenozoic Magmatism. Lithos, v.20,
    p.13-40.

DePAOLO, D.J. , 1979.
    Implications of correlated Nd and Sr isotopic variations for the
    chemical evolution of the crust and mantle. Earth and Planetary
    Science Letters, v.43, p.201-211.

DePAOLO, D.J. , 1981a.
    Trace element and isotopic effects of combined wall-rock
    assimilation and fractional crystallization. Earth and Planetary
    Science Letters, v.53, p.189-202 .

DePAOLO, D.J. , 1981b.
    A Nd and Sr isotopic study of the Mesozoic calc-alkaline granitic
    batholiths of the Sierra Nevada and Peninsular Ranges, California.
    Journal of Geophysical Research, v.B86, p.10470-10488.

DePAOLO, D.J. and WASSERBURG, G.J. , 1976.
    Nd isotopic variations and petrogenetic models. Geophysical Research
    Letters, v.3, p.249-252.

DICKINSON, W.R. , 1981.
    Plate tectonics through geological time. Philosophical Transactions
    of the Royal Society of London, v.A301, p.207-215.

DICKSON, W.L. , 1983.
    Geology, geochemistry and mineral potential of the Ackley granite
    and parts of the Northwest Brook and Eastern Meelpaeg Complexes
    southeast Newfoundland. Newfoundland Dept. Mines and Energy, Mineral
    Development Division, Report 83-6, 129 pp.

DICKSON, W.L., WILLIAMS, H., HAYES, J.P and TUACH, J. , 1988.
    Plutonic expression of Appalachian tectonostratigraphic zones in
    Newfoundland. Unpublished manuscript.

DICKSON, W.L., O'BRIEN, S.J. and HAYES, J.P. , 1989.
    Aspects of the mid-Paleozoic magmatic history of the south-central
    Hermitage flexure area, Newfoundland. Newfoundland Dept. Mines and
    Energy, Mineral Development Division, Report 89-1, p.81-95.

DIDIER, J., DUTHOU, J.L., and LAMEYRE, P. , 1982.
    Mantle and crustal granites: genetic classification of orogenic
    granites and their enclaves. Journal of Volcanology and Geothermal
    Research, v.14, p.125-132.

DINGWELL, D.B. , 1988.
    The structures and properties of fluorine-rich magmas : A review of
    experimental studies. In: Taylor, R.P and Strong, D.F (eds.): Recent
    Advances in the Study of Granite-Related Mineral Deposits. Canadian
    Institute of Mining and Metallurgy, p.1-12.

DOHERTY, R.A. , 1980.
    Geology of the Adlavik Islands. Newfoundland Dept. Mines and Energy,
    Mineral Development Division, Report 80-1, p. 161-165.

DOUGLAS, G.V. , 1953.
    Notes on localities visited on the Labrador coast in 1946 and 1947.
    Geological Survey of Canada, Paper 53-1, 67 pp.

DRUMMOND, B.J. and COLLINS, C.D.N. , 1986.
    Seismic evidence for underplating of the lower continental crust of
    Australia. Earth and Planetary Science Letters, v.79, p.361-372.

DUYVERMAN, H.J., HARRIS, N.B.W. and HAWKESWORTH, C.J. , 1982.
    Crustal accretion in the Pan-African : Nd and Sr isotope evidence
    from the Arabian Shield. Earth and Planetary Science Letters, v.59,
    p.315-326.

EMSLIE, R.F. , 1978.
    Anorthosite massifs, rapakivi granites and Late Proterozoic rifting
    of North America. Precambrian Research, v.7, p.61-98.

ERMANOVICS, I.F., KORSTGARD, J. and BRIDGEWATER, D. , 1982.
    Structural and lithological chronology of the Archean Hopedale block
    and adjacent Makkovik Subprovince, Labrador. Geological Survey of
    Canada, Paper 82-1B, p. 153-165.

ETHERIDGE, M.A., RUTLAND, R.W. and WYBORN, L.A. , 1987.
    Orogenesis and tectonic process in the Early to Middle Proterozoic
    of northern Australia. In: Kroner, A.(ed.). Proterozoic Lithospheric
    Evolution. American Geophysical Union, Geodynamic Series, v.17,
    p.115-130.

EVANS, D. , 1980.
    Geology and petrochemistry of the Kitts and Michelin Uranium
    deposits and related prospects, Central Mineral Belt, Labrador.
    Unpublished Ph.D. thesis, Queen's University, Kingston, Ontario, 311
    pp.

FARMER, G.L. and DePAOLO, D.J. , 1983.
    Origin of Mesozoic and Tertiary granite in the western United States
    and implications for pre-Mesozoic crustal structure. 1. Nd and Sr
    isotopic studies in the northern Great Basin. Journal of Geophysical
    Research, v.B88, p.3379-3401.

FAURE, G. , 1976.
    Principles of Isotope Geology. Wiley, New York.

FAUR , G. and POWELL, J.L. , 1972.
    S :rontium Isotope Geology. Springer-Verlag, Berlin, 188 pp.

FOWLER, M.B. , 1988.
    Ach'uaine hybrid appinite pipes: Evidence for mantle-derived
    shoshonitic parent magmas in Caledonian granite genesis. Geology,
    v.16, p.1026-1030.

FRYER, B.J. , 1984.
    Report on Geochronology for the Labrador Mapping Section.
    Newfoundland Dept. Mines and Energy, Mineral Development Division
    unpublished report, 34 pp.

FRYER, B.J. and TAYLOR, R.P. , 1985.
   Sm-Nd direct dating of the Collins Bay hydrothermal uranium deposit,
   Saskatchewan. Reply to comments by K.R.Ludwig. Geology, v.13, p.748.

FUMERTON, S.L., STAUFFER, M.R. and LEWRY J.F. , 1984.
   The Wathaman Batholith: largest known Precambrian pluton. Canadian
   Journal of Earth Sciences, v.21, p.1082-1097.

FYFE, W.S , 1988.
   Granites and a wet convecting ultramafic planet. Transactions of the
   Royal Society of Edinburgh, Earth Sciences, v.79, p.339-346.

GANDHI, S.S. , 1978.
   Geological Setting and genetic aspects of uranium occurrences in the
   Kaipokok Bay - Big River area, Labrador. Economic Geology, v.73,
   p.1492-1523.

GANDHI, S.S, GRASTY, R.L. and GRIEVE, R.A.F. , 1969.
   The geology and geochronology of the Makkovik Bay area, Labrador.
   Canadian Journal of Earth Sciences, v.6, p.1019-1034.

GANDHI, S.S, KROGH, T.E. and CORFU, F. , 1988.
   U-Pb zircon and titanite dates on two granitic intrusions of the
   Makkovik Orogen and a peralkaline granite of the Redwine Complex,
   central Labrador. Geological Association of Canada. Annual Meeting,
   St.John's, 1988. Program with abstracts, p. A42.

GARRETT, R.G. , 1983.
   Sampling methodology. In : Howarth, R.J. (ed): Statistics and Data
   Analysis in Geochemical Prospecting, Elsevier, Amsterdam, p.84-110.

GILL, F.D. , 1966.
   Petrography of molybdenite-bearing gneisses, Makkovik Area, Labrador
   (abstract). Canadian Mining Journal, v.89, p.100-101.

GLIKSON, A.Y. , 1983.
   Geochemical, isotopic, and paleomagnetic tests of early sial-sima
   patterns: The Precambrian crustal enigma revisited. In: Medaris,
   L.G. et al.(eds.): Proterozoic Geology. Geological Society of
   America, Memoir 161, p.95-118.

GOLDSTEIN, S.L., O'NIONS, R.K. and HAMILTON, P.J. , 1984.
   A Sm-Nd study of atmospheric dusts and particulates from major river
   systems. Earth and Planetary Science Letters, v.70, p.221-236.

GOWER, C.F. , 1981.
   The geology of the Benedict Mountains, Labrador. Newfoundland Dept.
   Mines and Energy, Mineral Development Division, Report 81-3, 26 pp.

GOWER, C.F. , 1985.
   Correlations between the Grenville Province and Sveconorwegian
   orogenic belt - Implications for Proterozoic Evolution of the
   southern margins of the Canadian and Baltic Shields. In: Tobi, A.C.
   and Touret, J. (eds.). The Deep Proterozoic Crust in the North
   Atlantic Provinces. NATO ASI Series, v.158, p.246-259.

GOWER, C.F. , 1986.
   Geology of the Double Mer White Hills and surrounding region,
   Grenville Province, Eastern Labrador. Geological Survey of Canada,
   Paper 86-15, 50 pp.

GOWER, C.F and OWEN, J.V. , 1984.
   Pre-Grenvillian and Grenvillian lithotectonic domains in Eastern
   Labrador -- Correlations with the Sveconorwegian Orogenic belt in
   Sweden. Canadian Journal of Earth Sciences, v.21, p.678-693.

GOWER, C.F. and RYAN, A.B. , 1986.
Proterozoic Evolution of the Grenville Province and adjacent
Makkovik Province in east-central Labrador. In: Moore et al., 1986
(eds.). The Grenville Province. Geological Association of Canada,
Special Paper 31, p.281-295.

GOWER, C.F. and RYAN, A.B. , 1987.
Two stage felsic volcanism in the Lower Proterozoic Upper Aillik
Group, Labrador, Canada: Its relationship to syn- and post-kinematic
plutonism. In: Pharoah et al. (eds). Geochemistry and mineralization
of Proterozoic Volcanic Suites. Geological Society Special
Publication 33, p.201-210.

GOWER, C.F., RYAN, A.B. , BAILEY, D.G. and THOMAS, A. , 1980.
The position of the Grenville Front in eastern and central Labrador.
Canadian Journal of Earth Sciences, v.17, p.784-788.

GOWER, C.F., FLANAGAN, M.J., KERR, A. and BAILEY, D.G. , 1982.
Geology of the Kaipokok Bay-Big River Area, Central Mineral Bel'.,
Labrador. Newfoundland Dept. Mines and Energy, Mineral Development
Division, Report 82-7. 77 pp.

GOWER, C.F., NEULAND, S., NEWMAN, M. and SMYTH, J. , 1987.
Geology of the Port Hope Simpson map region, Grenville Province,
eastern Labrador. Newfoundland Dept. Mines and Energy. Mineral
Development Division, Report 87-1, p.183-189.

GOWER, C.F., Van NOSTRAND, T., and SMYTH, J. , 1988.
Geology of the St.Lewis River map region, Grenville Province,
eastern Labrador. Newfoundland Dept. Mines and Energy. Mineral
Development Division, Report 88-1, p.59-73.

GRANT, N.K., VONER, F.R., MARZANO, M.C., HICKMAN, M.H. and
ERMANOVICS, I, 1983.
A summary of Rb-Sr isotope studies in the Archean Hopedale block and
the adjacent Makkovik Subprovince, Labrador. Geological Survey of
Canada, Current Research, Paper 83-1B, p.127-134.

GRAY, C.M. , 1984.
An isotopic mixing model for the origin of granitic rocks in
southeastern Australia. Earth and Planetary Science Letters, v.70,
p.47-60.

GREENE, B.A. , 1974.
An outline of the geology of Labrador. Newfoundland Dept. Mines and
Energy, Mineral Development Division, Information circular 15, 64
pp.

GROMET, L.P. and SILVER, L.T. , 1983.
Rare earth element distributions among minerals in a granodiorite
and their petrogenetic implications. Geochimica et Cosmochimica
Acta, v.47, p.925-939.

GURNIS, M. , 1988.
Large-scale mantle convection and the aggregation and dispersal of
supercontinents. Nature, v.332, p.695-699.

HALDEN, N.M., CLARK, G.S., LENTON, P.G., CORKERY, N.T and
SCHLEDWITZ, D., 1987.
Geochemical and isotopic constraints on the tectonic significance of
the Chipeweyan batholith, and Proterozoic magma genesis. Geological
Association of Canada, Annual Meeting, Saskatoon, 1987, Program with
abstracts, p.A51.

HALLIDAY, A.N. , 1984.
Coupled Sm-Nd and U-Pb systematics in late Caledonian granites and
the basement under northern Britain. Nature, v.307, p.229-233.

HANSON, G.N. , 1978.
   The application of trace elements to the petrogenesis of igneous
   rocks of granitic composition. Earth and Planetary Science Letters,
   v.38, p.26-43.

HARRIS, N.B.W. and MARRINER, G.F. , 1980.
   Geochemistry and petrogenesis of a peralkaline granite complex from
   the Midian Mountains, Saudi Arabia. Lithos, v.13, p.325-337.

HARRIS, N.B.W., PEARCE, J.A. and TINDLE, A.G. , 1984.
   Geochemical characteristics of collision-zone magmatism. In: Coward,
   M.P., and Reis, A.C.(eds.). Collision Tectonics. Geological Society
   Special Publication 19, p.67-81.

HAWKESWORTH, C.J., MENZIES, M.A. and van CALSTEREN, P. , 1986.
   Geochemical and tectonic evolution of the Damara Belt, Namibia. In:
   Coward, M.P. and Reis, A.C. (eds.). Collision Tectonics. Geological
   Society Special Publication 19, p.305-319.

HAYES, J.P., DICKSON, W.L. and TUACH, J. , 1987.
   Newfoundland granitoid rocks: Map with marginal notes. Newfoundland
   Dept. Mines and Energy, Mineral Development Division, Open File
   87-85.

HILDRETH, E.W. , 1979.
   The Bishop Tuff: Evidence for the origin of compositional zonation
   in silicic magma chambers. Geological Society of America, Special
   Paper 180, p.43-76.

HILDRETH, E.W. , 1981.
   Gradients in silicic magma chambers: Implications for lithospheric
   magmatism. Journal of Geophysical Research, v.B86, p.10153-10192.

HILDRETH, E.W. , 1987.
   Essay Review: Magmatism at a plate edge. Tectonophysics, v.140,
   p.335-339.

HILDRETH, E.W and MOORBATH, S. , 1988.
   Crustal contributions to arc magmatism in the Andes of central
   Chile. Contributions to Mineralogy and Petrology, v.98, p.455-489.

HILL, J.D. , 1982.
   Geology of the Flowers River - Notokwanon River area, Labrador
   Newfoundland Dept. Mines and Energy, Mineral Development Division
   Report 82-6, 137 pp.

HILL, J.D. , 1988.
   Ring-complex features in the Neohelikian Flowers River Igneous
   Suite, southeastern Nain Complex, Labrador. Geological Association
   of Canada. Annual Meeting, St.John's, Nfld, 1988. Program with
   abstracts, p.A56.

HILL, J.D. and THOMAS, A. , 1983.
   Correlation of two Helikian peralkaline granite-volcanic centres in
   central Labrador. Canadian Journal of Earth Sciences, v.20,
   p.753-763.

HOFFMAN, P.F. , 1973.
   Evolution of an Early Proterozoic continental margin: The Coronation
   Geosyncline and associated aulacogens of the northwest Canadian
   Shield. Philosophical Transactions of the Royal Society of London,
   v.A273, p.547-581.

HOFFMAN, P.F. , 1980.
    The Wopmay Orogen: A Wilson cycle of early Proterozoic age in the
    north west of the Canadian Shield. In: Strangway, D.W (ed.). The
    Continental Crust and its Mineral Deposits. Geological Association
    of Canada, Special Paper 20, p.523-553.

HOFFMAN, P.F. , 1988.
    United plates of America, the birth of a craton: Early Proterozoic
    assembly and growth of Proto-Laurentia. Annual Reviews of Earth and
    Planetary Sciences, v.16, p.543-603.

HOFFMAN, P.F. , 1989.
    Speculations on Laurentia's first gigayear (2.0 to 1.0 Ga). Geology,
    v.17, p.135-138.

HUGHES, C.J. , 1973.
    Spilites, keratophyres and the igneous spectrum. Geological
    Magazine, v.109, p.513-527.

HYNES, A. , 1982.
    Stability of the oceanic tectosphere - A model for early Proterozoic
    intercratonic orogeny. Earth and Planetary Science Letters, v.61,
    p.333-345.

HYNES, A. and FRANCIS, D. , 1982.
    Komatiitic basalts of the Cape Smith Fold Belt, New Quebec, Canada.
    In: Arndt, N.T. and Nisbet, E.G.(eds.). Komatiites. Allen and Unwin,
    p.159-170.

IRVINE, T.N. and BARAGAR, W.R. , 1971.
    A guide to the chemical classification of the common volcanic rocks.
    Canadian Journal of Earth Sciences, v.8, p.523-548.

JACKSON, N.J. , 1986.
    Petrogenesis and evolution of Arabian felsic plutonic rocks. Journal
    of African Earth Sciences, v.4, p.47-59.

JACKSON, N.J., WALSH, J.N. and PEGRAM, E. , 1984.
    Geology, geochemistry and petrogenesis of late Precambrian
    granitoids in the Central Hijaz region of the Arabian Shield.
    Contributions to Mineralogy and Petrology, v.87, p.205-219.

JACOBSEN, S.B. and WASSERBURG, G.J. , 1980.
    Sm-Nd isotopic evolution of chondrites. Earth and Planetary Science
    Letters, v.50, p.139-155.

JAKES, P. and WHITE, A.J.R. , 1972.
    Major and trace element abundance in volcanic rocks of orogenic
    areas. Bulletin of the Geological Society of America, v.83,
    p.29-39.

JAMES, R.S. and HAMILTON, D.L. , 1969.
    Phase relations in the system albite-orthoclase-anorthite-quartz at
    1 Kilobar water vapour pressure. Contributions to Mineralogy and
    Petrology, v.21, p.111-141.

JARL, L.G. and JOHANSSON, A. , 1988.
    U-Pb zircon ages of granitoids from the Smaland-Varmland granite
    porphyry belt, southern and central Sweden. Geologiska Foreningens i
    Stockholm Forhandlingar, v.110, p.21-28.

JENNER, G.A. , 1984.
    Partition coefficients used in trace element modelling. Course notes
    for Earth Science 6510, Memorial University, St.John's,
    Newfoundland. Unpublished compilation of data.

JOHANNSEN, A. , 1920.
   A quantitative mineralogical classification of igneous rocks.
   Journal of Geology, v.28, p.38-60.

KAY, S.M., RAMOS, V.A., MPOZODIS, C. and SRUOGA, P. , 1989.
   Late Paleozoic to Jurassic silicic magmatism at the Gondwana margin:
   Analogy to the Middle Proterozoic in North America ? Geology, v.17,
   p.324-328.

KEEN, C.E., WARDLE, R.J., GOWER, C.F., WOODSIDE, J., HALL, J.,
SRIVASTAVA, S.P. and LOUDEN, K., 1988.
   The Eastern Canadian Shield Offshore Transect (ECSOT). Unpublished
   project proposal to Lithoprobe East, 46 pp.

KERR, A. , 1986.
   Plutonic rocks of the eastern Central Mineral Belt, Labrador:
   General geology and description of regional granitoid units.
   Newfoundland Dept. Mines and Energy, Mineral Development Division,
   Report 86-1, p.89-100.

KERR, A. , 1987a.
   Plutonic rocks of the eastern Central Mineral Belt, Labrador:
   Lithogeochemical patterns and the identification of potential
   specialized granitoids. Newfoundland Dept. Mines and Energy, Mineral
   Development Division, Report 87-1, p.15-36.

KERR, A. , 1987b.
   Geochemistry and mineral potential of evolved granitoid rocks and
   layered mafic intrusions within the Trans-Labrador Batholith,
   eastern Labrador. Newfoundland Dept. Mines and Energy, Mineral
   Development Division, Report of Activities for 1987, p.42-48.

KERR, A. , 1988.
   Geochemical characteristics and mineral potential of specialized
   granitoid plutons in the Trans-Labrador batholith, eastern Labrador.
   Newfoundland Dept. Mines and Energy, Mineral Development Division,
   Report 88-1, p.15-36.

KERR, A. , in press.
   Geochemistry of the Trans-Labrador Granitoid Belt, Canada: A
   quantitative comparative study of a Proterozoic batholith and
   possible Phanerozoic counterparts. Precambrian Research, special
   volume from a Proterozoic Geochemistry symposium in Lund, Sweden,
   1987.

KERR, A. and FRYER, B.J., in press.
   Sources of Early Proterozoic magmas in the Makkovik Province of
   eastern Labrador: Evidence from Nd isotope data. Geological
   Association Of Canada, Special Paper on the Middle Proterozoic
   Evolution of the Laurentian and Baltic Shields.

KING, A.F. , 1963.
   Geology of the Cape Makkovik peninsula, Aillik, Labrador.
   Unpublished M.Sc. thesis, Memorial University, St.John's,
   Newfoundland, 114 pp.

KINNAIRD, J and BOWDEN, P. , 1987.
   African anorogenic alkaline magmatism and mineralization: A
   discussion with reference to the Niger-Nigerian province. Geological
   Journal, v.22, p.297-341.

KORSTGARD, J. and ERMANOVICS, I. , 1985.
   Tectonic evolution of the Hopedale Block and the adjacent Makkovik
   Subprovince, Labrador, Newfoundland. In: Ayres et al.(eds).
   Evolution of Archean Supracrustal Sequences. Geological Association
   of Canada, Special Paper 28, p.223-239.

KRANCK, E.N. , 1939.
    Bedrock geology of the seaboard region of Newfoundland and Labrador.
    Geological Survey of Newfoundland, Bulletin 19, 44pp.

KRANCK, E.N. , 1953.
    Bedrock geology of the seaboard of Labrador between Domino Run and
    Hopedale, Newfoundland. Geological Survey of Canada, Bulletin 26,
    41pp.

KROGH, T.E. , 1985.
    Determination of U-Pb zircon and sphene ages. Newfoundland Dept.
    Mines and Energy, Mineral Development Division, Open File LAB (506).

KROGH, T.E., SCHARER, U., KWOK, Y.Y and KERR, A. , in preparation.
    U-Pb zircon geochronology of Early and Middle Proterozoic plutonic
    rocks in the Makkovik Province, Labrador, Canada.

KRONER, A.J.(Editor) , 1981.
    Precambrian plate tectonics. Elsevier, Amsterdam. 782 pp.

KRONER, A. , 1983.
    Proterozoic mobile belts compatible with the plate tectonic process.
    In: Medaris,L.G. et al.(eds). Proterozoic Geology. Geological
    Society Of America, Memoir 161, p.59-75.

LA ROCHE, H., LETERRIER, J., GRANDCLAUDE, P., and MARCHAL, M. , 1980.
    A classification of volcanic and plutonic rocks using R1-R2 diagrams
    and major element analyses. Chemical Geology, v.29, p.183-210.

LAGERBLAD, B., TRAGARDH, J., RIPA, M. and GORBATSCHEV, R. , 1987.
    Bergslagen field excursion guide. IGCP Project 217 (Proterozoic
    Geochemistry). Lund, Sweden, June 1987. Field trip guide and summary
    of geology. 68 pp.

LANORD, C.F. and LeFORT, P. , 1988.
    Crustal melting and granite genesis during the Himalayan collision
    orogenesis. Transactions of the Royal Society of Edinburgh, Earth
    Sciences, v.79, p.183-195.

LeMAITRE, R.W. , 1976.
    The chemical variability of some common igneous rocks. Journal of
    Petrology, v.17, p.589-637.

LETERRIER, J., MARCHAL, M., DUBUIT, M. and DREUX, G. , 1983.
    La banque de donnees geochimiques ARTEMISE (analyses roches totales,
    mineraux, sols et eaux) exemples de valorisation scientifique.
    Bulletin Societe Geologique de France, v.25, p.697-704.

LEWRY, J.F. , 1981.
    Lower Proterozoic arc-microcontinent collisional tectonics in the
    Western Churchill Province. Nature, v.294, p.69-72.

LEWRY, J.F.; STAUFFER, M.R. and FUMERTON, S. , 1981.
    A Cordilleran-type batholithic belt in the Churchill Province .n
    Northern Saskatchewan. Precambrian Research, v.14, p. 277-313

LIEBER, O.M. , 1860.
    Notes on the geology of the coast of Labrador. Report of the United
    States Coastal Survey for 1860, p.402-408.

LINDH, A. , 1987.
    Westward growth of the Baltic Shield. Precambrian Research, v.35,
    p.53-70.

LINTHOUT, K. , 1984.
    Alkali-zirconosilicates in peralkaline rocks. Contributions to
    Mineralogy and Petrology, v.86, p.155-158.

LIPMAN, P.W. , 1988.
    Evolution of silicic magma in the upper crust: The mid-Tertiery
    Latir volcanic field and its cogenetic granitic batholith, northern
    New Mexico, U.S.A. Transactions of the Royal Society of Endinburgh,
    Earth Sciences, v.79, p.265-288.

LOISELLE, M.C., and WONES, D.R. , 1979.
    Characteristics and origin of anorogenic granites. Geological
    Society of America, programs with abstracts, v.11, p.468.

LONGERICH, H.L., JACKSON, S.E., JENNER, G.A. and FRYER, B.J.,
in preparation.
    Inductively coupled plasma mass spectrometric analysis of rocks.
    Part 1 : Determination of 33 trace elements, including the rare
    earths, using a standard addition procedure, standardless
    calibration, and naturally occurring internal standards.

LOVERIDGE, W.D., ERMANOVICS, I.F., and SULLIVAN, R.W. , 1987.
    U-Pb ages on zircon from the Maggo Gneiss, the Kanairiktok Plutonic
    Suite and the Island Harbour Plutonic Suite, coast of Labrador,
    Newfoundland. In: Radiogenic Age and Isotopic Studies; Report 1,
    Geological Survey of Canada, Paper 87-2, p.59-65.

LYELL, Charles, Sir , 1885.
    The Student's Elements Of Geology. Fourth Edition, revised. John
    Murray, London, 621 pp.

MacDONALD, R. and SMITH, R.L. , 1988.
    Relationships between silicic plutonism and volcanism: geochemical
    evidence. Transactions of the Royal Society of Edinburgh, Earth
    Sciences, v.79, p.257-265.

MACDOUGALL, C.S. , 1988.
    A metallogenic study of polymetallic, granophile mineralization
    within the Early Proterozoic Upper Aillik Group, Round Pond area,
    Central Mineral Belt, Labrador. Unpublished M.Sc. Thesis, Memorial
    University, St.John's, Newfoundland, 187 pp.

MacDOUGALL, C.S., and WILTON, D.H. , 1987.
    Middle Proterozoic granite-related mineralization in the Round Pond
    area, Labrador. Geological Survey of Canada, Current Research,
    Report 87-1A, p.457-466.

MacDOUGALL, C.S., and WILTON, D.H. , 1988.
    Geology of radioactive zones in the Round Pond area, Labrador.
    Geological Survey of Canada, Current Research, Report 88-1C,
    p.271-275.

MacKENZIE, L.M. , 1988.
    Geology and mineralization of the Burnt Lake area, Central Mineral
    Belt, Labrador. Unpublished M.Sc. thesis, Memorial University,
    St.Johns, Newfoundland.

MacKENZIE, L.M. and WILTON, D.H. , 1987.
    Uranium, molybdenum and base-metal sulphide mineralization in the
    Burnt Lake area, central Labrador: three different styles of ore
    formation. Geological Survey of Canada, Current Research, Report
    87-1A, p.467-476.

MacKENZIE, L.M., and WILTON, D.H. , 1988.
    The Grenville Province boundary in the Burnt Lake area, Central
    Mineral Belt of Labrador. Geological Survey of Canada, Current
    Research, Report 88-1C, p.233-237.

MARSH, B.D. , 1988.
    Crystal capture, sorting, and retention in convecting magmas.
    Bulletin of the Geological Society of America, v.100, p.1720-1737.

MARTEN, B.E. , 1977.
    The relationship between the Aillik Group and the Hopedale Gneiss
    Kaipokok Bay, Labrador. Unpublished Ph.D. thesis, Memorial
    University, St.John's, Newfoundland, 389 pp.

MARTIN, R.F. and PIWINSKI, A.J. , 1972.
    Magmatism and tectonic settings. Journal of Geophysical Research,
    v.B77, p.4966-4975.

McCARTHY, T.S. and HASTY, R.A. , 1976.
    Trace element distribution patterns and their rel·tionship to the
    crystallization of granitic melts. Geochimica et ·:osmochimica Acta,
    v.40, p. 1351-1358.

McCONNELL, J. , 1986.
    Exploration geochemical studies of Labrador granitoids. Newfoundland
    Dept. Mines and Energy. Mineral Development Division, Report 86-1,
    p.219-220.

McCULLOCH, M.T., and CHAPPELL, B.W. , 1982.
    Nd isotopic characteristics of S- and I- type granites. Earth and
    Planetary Science Letters, v.58, p.51-64.

McCULLOCH, M.T. and BLACK, L.P. , 1984.
    Sm-Nd systematics of Enderby Land granulites and evidence for the
    redistribution of Sm and Nd during metamorphism. Earth and Planetary
    Science Letters, v.71, p.46-58.

MEDARIS, L.G., BYERS, C.W., MICKELSON, D.M. and SHANKS, W.C. (Editors),
1983.
    Proterozoic Geology: Selected papers from an international
    Proterozoic symposium. Geological Society Of America, Memoir 161.

MICHAEL, P.J. , 1983.
    Chemical differentiation of the Bishop Tuff and other high-silica
    magmas through crystallization processes. Geology, v.11, p.31-34.

MILLER, C.F. and MITTLEFEHLDT, D.W. , 1982.
    Depletion of light rare-earth elements in felsic magmas. Geology,
    v.10, p.129-133.

MITTLEFEHLDT, D.W. and MILLER, C.F. , 1983.
    Geochemistry of the Sweetwater Wash pluton, California :
    Implications for "anomalous" trace element behaviour during
    differentiation of felsic magmas. Geochimica et Cosmochimica Acta,
    v.47, p.109-124.

MORRISON, G.W. , 1980.
    Characteristics and setting of the shoshonite rock association.
    Lithos, v.13, p.97-108.

MULLAN, H.S. and BUSSELL, M.A. , 1977.
    The basic rock series in batholithic associations. Geological
    Magazine, v.114, p.265-280.

MUNOZ, J.B. and STERN, C.R. , 1989.
    Alkaline magmatism within the segment 38-39 S of the Plio-Quaternary
    volcanic belt of the southern South American continental margin.
    Journal of Geophysical Research, v.B94, p.4545-4560.

NARANJO, J.A., PUIG, A. and SUAREZ, M. , 1986.
    A note on lower Jurassic magmatism in the coastal cordillera of
    Atacama, Chile. Geological Magazine, v.123, p.699-702.

NELSON, B.K. and DePAOLO, D.J. , 1984.
 1700 Myr greenstone volcanic successions in southwestern North
 America and isotopic evolution of the Proterozoic mantle. Nature,
 v.312, p.143-146.

NUNN, G.A.G., THOMAS, A. and KROGH, T.E. , 1985.
 The Labradorian Orogeny : Geochronological database. Newfoundland
 Dept. Mines and Energy, Mineral Development Division, Report 85-1,
 p.43-54.

NUNN, G.A. and STAFF, Labrador Section. In preparation.
 1:1,500,000 scale interim geological map of Labrador. Newfoundland
 Dept. Mines and Energy. Geological Survey Branch. Scheduled for
 release in 1989 or 1990.

NURMI, P.A. and HAAPALA, I. , 1986.
 The Proterozoic granitoids of Finland : Granite types, metallogeny
 and relation to crustal evolution. Bulletin of the Geological
 Society of Finland, v.58, p.203-233.

NYSTROM, J.O. , 1982.
 Post-Svecokarelian andinotype evolution in Central Sweden.
 Geologisches Rundschau, v.71, p.141-157.

O'HARA, M.J. , 1977.
 Geochemical evolution during fractional crystallization of a
 periodically refilled magma chamber. Nature, v.266, p.503-507.

O'NIONS, R.K., CARTER, S.R., EVENSON, N.M. and HAMILTON, P.J. , 1979.
 Geochemical and cosmochemical applications of Nd isotope analysis.
 Annual Reviews of Earth and Planetary Science, v.7, p.11-38.

OWEN, J.V., RIVERS, T. and GOWER, C.F. , 1986.
 The Grenville Front on the Labrador coast. In: Moore et al., 1986
 (eds). The Grenville Province. Geological Association of Canada,
 Special Paper 31, p.95-107.

OWEN, J.V., DALLMEYER, R.D., GOWER, C.F., and RIVERS, T. , 1988.
 Metamorphic conditions and 40Ar/39Ar geochronologic contrasts across
 the Grenville Front Zone, coastal Labrador, Canada. Lithos, v.21,
 p.13-35.

PACKARD, A.S. , 1891.
 The Labrador Coast. Hodges, New York, 513pp.

PAGE, R.W. , 1988.
 Geochronology of Early to Middle Proterozoic fold belts in northern
 Australia: A review. Precambrian Research, v.41, p.1-19.

PALLISTER, J.S., STACEY, J.S., FISCHER, L.B. and PREMO, W.R. , 1987.
 Arabian Shield ophiolites and Late Proterozoic microplate accretion.
 Geology, v.15, p.320-323.

PANKHURST, R.J., HOLE, M.J. and BROOK, M. , 1988.
 Isotopic evidence for the origin of Andean granites. Tran.actions of
 the Royal Society of Edinburgh, Earth Sciences, v.79, p.123-133.

PATCHETT, P.J. and BRIDGWATER, D. , 1984.
 Origin of continental crust of 1.9-1.7 Ga age defined by Nd isotopes
 in the Ketilidian terrain of South Greenland. Contributions to
 Mineralogy and Petrology, v.87, p.311-318.

PATCHETT, P.J. and ARNDT, N.T. , 1986.
 Nd isotopes and tectonics of 1.9-1.7 Ga crustal genesis. Earth and
 Planetary Science Letters, v.78, p.329-338.

PATCHETT, P.J. and KOUVO, O. , 1986.
Origin of continental crust of 1.9-1.' Ga age: Nd isotopes and U-Pb
zircon ages in the Svecokarelian terrain of South Finland.
Contributions to Mineralogy and Petrology, v.92, p.1-12.

PATERSON, S.R. and TOBISCH, O.T , 1988.
Using pluton ages to date regional deformations: Problems with
commonly used criteria. Geology, v.16, p.1108-1111.

PAYETTE, C. and MARTIN, R.F. , 1986.
The glass inclusions and mineralogy of rhyolites, Upper Aillik
Group, Labrador. Unpublished report to the Geological Survey of
Canada, 98 pp.

PEACOCK, M.A. , 1931.
Classification of igneous rock series. Journal of Geology, v.39,
p.54-67.

PEARCE, J.A. and CANN, J.R. , 1973.
Tectonic setting of basic volcanic rocks investigated using trace
element analyses. Earth and Planetary Science Letters, v.19,
p.290-300.

PEARCE, J.A., HARRIS, N.B.W. and TINDLE, A.G. , 1984.
Trace element discrimination diagrams for the tectonic
interpretation of granitic rocks. Journal of Petrology, v.25,
p.956-974.

PETRO, W.L., VOGEL, T.A. and WILBRAND, J.T. , 1979.
Major element chemistry of plutonic rock suites from compressional
and extensional plate boundaries. Chemical Geology, v.26, p.217-235.

PHAROAH, T.C., BECKINSALE, R.D. and RICKARD, D. (editors) , 1987.
Geochemistry and Mineralization of Proterozoic Volcanic Suites.
Geological Society Special Publication 33, 560 pp.

PIPER, J.D.A. , 1983.
Dynamics of the continental crust in Proterozoic times. In: Medaris
et al.(Eds.). Proterozoic Geology. Geological Society of America,
Memoir 161, p.11-35.

PITCHER, W.S. , 1977.
The anatomy of a batholith. Journal of the Geological Society of
London, v.135, p.157-182.

PITCHER, W.S , 1983.
Granite type and tectonic environment. In: Hsu, K.(ed), Mountain
Building Processes, Academic Press, London, p.19-44.

PITCHER, W.S. and BERGER, A.R. , 1972.
The geology of Donegal: A study of granite emplacement and
unroofing. Wiley, New York, 435 pp.

PITCHER, '.S., ATHERTON, M.P., COBBING, E.J. and BECKINSALE, R.D. ,
1985.
Magmat.sm at a Plate Edge: The Peruvian Andes. Wiley, New York. 330
pp.

PRATT, T. and Numerous Others , 1988.
COCORP profiling of the midcontinent of North America: Overview and
Proterozoic layered rocks. EOS (American Geophysical Union
Transactions), v.69, p.496.

PUSHKAR, P., McBIRNEY, A.R. and KUDO, A.M. , 1972.
   The isotopic composition of Sr in Central American ignimbrites.
   Bulletin Volcanologique, v.35, p.265-294.

RAMOS, V.A. , 1988.
   Late Pyotepsodes; Early Paleesote of South America - A collisional

RAMOS, V.A., JORDAN, T.E., ALLMENDINGER, R.W., MPOZODIS, C., KAY, S.M.,
CORTES, J.M. and PALMA, M., 1986.
   Paleozoic terranes of the central Argentine-Chilean Andes.
   Tectonics, v.5, p.855-880.

RAPELA, C.W. and KAY, S.M. , 1988.
   Late Paleozoic to recent magmatic evolution of northern Patagonia.
   Episodes, v.11, p.175-181.

READ, H.H. and WATSON, J., 1975.
   Later Stages in Earth History. MacMillan Press, London, 371 pp.

REYMER, A. and SCHUBERT, G. , 1986.
   Rapid growth of some major segments of continental crust. Geology,
   v.14, p.299-302.

RICE, A. , 1981.
   Convective fractionation: A mechanism to provide cryptic zoning
   (macrosegregation), layering, crescumulates, banded tuffs and
   explosive volcanism in igneous processes. Journal of Geophysical
   Research, v.B86, p.405-417.

RYAN, A.B. , 1984.
   Regional geology of the central part of the Central Mineral belt,
   Labrador. Newfoundland Dept. Mines and Energy, Mineral Development
   Division, Memoir 3, 185 pp.

RYAN, A.B. and HARRIS, A. , 1978.
   Geology of the Otter-Nipishish-Stipec Lakes area, Labrador.
   Newfoundland Dept. Mines and Energy, Mineral Development Division,
   Report 78-1, p. 63-70.

RYAN, A.B. and KAY, A. , 1982.
   Basment-cover relationships and plutonic rocks in the Makkovik
   subprovince, north of Postville, coastal Labrador. Newfoundland
   Dept. Mines and Energy, Mineral Development Division, Report 82-1,
   p. 109-121.

RYAN, A.B., KAY, A. and ERMANOVICS, I. , 1983.
   The geology of the Makkovik Subprovince between Kaipokok Bay and Bay
   of Islands, Labrador. Newfoundland Dept. Mines and Energy, Mineral
   Development Division, Maps 83-38 and 83-41 (notes), 21 pp.

RYAN, A.B., BARAGAR, W.R.A., and KONTAK, D.J. , 1987.
   Geochemistry, tectonic setting and mineralization of high-potassium
   middle Proterozoic rocks in central Labrador, Canada. In: Pharoah et
   al.(eds.). Geochemistry and Mineralization of Proterozoic Volcanic
   Suites. Geological Society Special Publication 33, p.241-254.

SALVADOR, A., (Chairman) , 1987.
   Stratigraphic classification and nomenclature of igneous and
   metamorphic rock bodies. Bulletin of the Geological Society of
   America, v.99, p.440-442.

SAUNDERS, A.D, TARNEY, J., MARSH, N.G. and WOOD, D.A. , 1979.
   Ophiolites as ocean crust or marginal basin crust : A geochemical
   approach. Proceedings of an International Ophiolite Symposium.
   Geological Survey of Cyprus. p. 193-205.

SCHÄRER, U. , 1988.
Origin and evolution of Proterozoic crust in eastern Labrador.
Geological Association of Canada. Annual Meeting, St. John's.
Program with abstracts, v.13, p.A109.

SCHÄRER, U., and GOWER, C.F., 1988.
Crustal evolution in eastern Labrador: constraints from precise U-Pb
ages. Precambrian Research, v.38, p.405-421.

SCHÄRER, U., KROGH, T.E. and GOWER, C.F. , 1986.
Age and Evolution of the Grenville Province in eastern Labrador from
U-Pb systematics in accessory minerals. Contributions to Mineralogy
and Petrology, v.94, p.428-451.

SCHÄRER, U., KROGH, T.E., WARDLE, R.J., RYAN, A.B. and GANDHI, S.S. ,
1988.
U-Pb ages of Early and Middle Proterozoic volcanism and metamorpism
in the Makkovik Orogen, Labrador. Canadian Journal of Earth
Sciences, v.25, p.1098-1107.

SCOTT, D.J., ST-ONGE, M.R., LUCAS, S.B. and HAELMSTEDT, H. , 1989.
The 2.00 Ga Purtiniq ophiolite: imbricated and metamorphosed oceanic
crust in the Cape Smith thrust-fold belt, New Quebec. Geological
Association of Canada, Annual Meeting, Montreal, 1989. Programs with
abstracts, v.14, p.A57.

SEARLE, M.P. and FRYER, B.J. , 1988.
Garnet, tourmaline and muscovite-bearing leoucogranites, gneisses
and migmatites of the higher Himalayas from Zanskar, Kulu, Lahoul
and Kashmir. In; Coward, M.P. and Reis, A.C. (Eds.). Collision
Tectonics. Geological Society Special Publication 19, p.185-201.

SHAND, S.J. , 1927.
Eruptive Rocks. Thomas Murby and Co., London, 360 pp.

SILVER, L.T. and CHAPPELL, B.W. , 1988.
The Peninsular Ranges Batholith : an insight into the evolution of
the Cordilleran batholiths of southwestern North America.
Transactions of the Royal Society of Edinburgh, Earth Sciences,
v.79, p.105-121.

SIMS, P.K., KISVARSANYI, E.B. and MOREY, G.B. , 1987.
Geology and metallogeny of Archean and Proterozoic basement terranes
in the northern midcontinent U.S.A.: An overview. United States
Geological Survey, Bulletin 1815, 51 pp.

SLOMAN, L.E. , 1989.
Triassic shoshonites from the Dolomites, northern Italy: Alkaline
arc rocks in a strike-slip setting. Journal of Geophysical Research,
v.B94, p.4655-4666.

SMYTH, W.R., MARTEN, B.E. and RYAN, A.B. , 1978.
A major Aphebian - Helikian unconformity wit·in the Central Mineral
Belt of Labrador: Definition of new groups an1 metallogenic
implications. Canadian Journal of Earth Sciences, v.15, p.1954-1966.

SPARKS, R.S.J. , 1986.
The role of crustal contamination in magma evolution through
geological time. Earth and Planetary Science Letters, v.78,
p.211-223.

STEIGER, R.H. and JAGER, E. , 1977.
Subcommission on geochronology: convention on the use of decay
constants in geochronology and cosmochronology. Earth and Planetary
Science Letters, v.36, p.359-362.

STEINHAUER, H. , 1814.
    Notes on the geology of the Labrador coast. Transactions of the
    Geological Society, v.2, p.486-491.

STEVENSON, I.M. , 1970.
    Rigolet and Groswater Bay areas, Newfoundland (Labrador). Geological
    Survey of Canada, Paper 69-49, 24 pp.

STEVENSON, R.K. and PATCHETT, P.J. , 1988.
    Nd isotopic data for Archean granitoids in the Portman Lake area,
    Northwest Territories, Canada. Geological Association of Canada,
    Annual Meeting, St.John's, 1988. Program with abstracts, p. A118.

STEWART, D.B. , 1959.
    Rapakivi granite from eastern Penobscot Bay, Maine. Proceedings of
    the 20th International Geological Congress, Mexico City. Petrology
    and Geochemistry, p.293-320.

STOCKWELL, C.H. , 1972.
    Revised Precambrian time scale for the Canadian Shield. Geological
    Survey of Canada, Paper 72-52, 4 pp.

STOESER, D.B. , 1986.
    Distribution and tectonic setting of plutonic rocks of the Arabian
    Shield. Journal of African Earth Sciences, v.4, p.21-46.

STOESER, D.B. and CAMP, V.E. , 1985.
    Pan-African microplate accretion of the Arabian Shield. Bulletin of
    the Geological Society of America, v.96, p.817-826.

STRECKEISEN, A.L , 1976.
    To each plutonic rock its proper name. Earth Science Reviews, v.12,
    p.1-33.

STRECKHEISEN, A.L. and LEMAITRE, R.W. , 1979.
    Chemical approximation to modal QAPF classification of the igneous
    rocks. Neues Jahrbuch Mineral Abn, v.136, p. 169-206.

STRONG, D.F. , 1980.
    Granitoid rocks and associated mineral deposits of eastern Canada
    and western Europe. In: Strangway, D.W.(Ed.). The Continental Crust
    and its Mineral Deposits. Geological Association of Canada, Special
    Paper 20, p.741-771.

STRONG, D.F. , 1981.
    Ore deposit models : A model for granophile mineral deposits.
    Geoscience Canada, v.8, p.154-161.

STRONG, D.F., DICKSON, W.L., O'DRISCOLL, C.F. and KEAN, B.F. , 1974.
    Geochemistry of eastern Newfoundland granitoid rocks. Newfoundland
    Dept. Mines and Energy, Mineral Development Division, Report 74-3,
    140 pp.

SUTTON, J. , 1963.
    Long-term cycles in the evolution of continents. Nature, v.198,
    p.731-735.

SUTTON, J.S. , 1972.
    The Precambrian gneisses and supracrustal rocks of the western shore
    of Kaipokok Bay, Labrador. Canadian Journal of Earth Sciences, v.9,
    p.1677-1692.

SYLVESTER, P.J. , 1989.
    Post-collisional alkaline granites. Journal of Geology, v.97,
    p.261-280.

TATSUMI, Y. , 1989.
Migration of fluid phases and genesis of basalt magmas in subduction zones. Journal of Geophysical Research, v.B94, p.4697-4707.

TAYLOR, F.C. , 1975.
Geology, Makkovik area. Geological Survey of Canada, Map 1444A.

TAYLOR, R.P and FRYER, B.J. , 1982.
Rare Earth Element geochemistry as an aid to interpreting hydrothermal ore deposits. In: Evans, A.M. (ed.). Metallization Associated With Acid Magmatism. Wiley, London. p.357-365.

TAYLOR, S.R. and McCLENNAN, S.M. , 1985.
The Continental Crust: its Composition and Evolution. An Examination of the Geochemical Record Preserved in Sedimentary Rocks. Blackwell Scientific Publications. 312 pp.

THIRLWALL, M.F. , 1982.
Systematic variation in chemistry and Nd-Sr isotopes across a Caledonian calc-alkaline volcanic arc: implications for source materials. Earth and Planetary Science Letters, v.58, p.27-50.

THOMAS, A. , NUNN, G. and WARDLE, R.J. , 1985.
A 1650 Ma orogenic belt within the Grenville Province of northeastern Canada. In:Tobi, A. and Touret, L.(eds): The deep Proterozoic crust in the north Atlantic provinces. NATO ASI series, v.158, p.151-161.

THOMAS, A. , NUNN, G.A.G., and KROGH, T.E. , 1986.
The Labradorian Orogeny: Evidence for a newly identified 1600 to 1700 Ma orogenic event in Grenville Province crystalline rocks from Central Labrador. In: Moore et al., 1986 (eds). The Grenville Province. Geological Association of Canada, Special Paper 31, p.175-189.

TUACH, J., DAVENPORT, P.H., DICKSON, W.L. and STRONG, D.F. , 1986.
Geochemical trends in the Ackley Granite, southeast Newfoundland: Their relevance to magmatic metallogenic processes in high-silica granitoid systems. Canadian Journal of Earth Sciences, v.23, p.747-765.

TUTTLE, O.F. and BOWEN, N.L. , 1958.
Origin of granite in the light of experimental studies in the system NaAlSi3O8-KAlSi3O8-SiO2-H2O. Geological Society of America, Memoir 74, 153 pp.

VAN SCHMUS, W.R. and BICKFORD, M.E. , 1981.
Proterozoic chronology and evolution of the midcontinent region of North America. In: Kroner, A. (ed). Precambrian Plate Tectonics, p.261-296. Elsevier, Amsterdam.

VIDAL, P., COCHERIE, A. and LeFORT, P. , 1982.
Geochemical investigations of the origin of the Manaslu leucogranite (Himalaya, Nepal). Geochimica et Cosmochimica Acta, v.64, p.2274-2292.

VILLEMANT, B., JAFFREZIC, H., JORON, J-L., and TREUIL, M. , 1981.
Distribution coefficients of major and trace elements, fractional crystallization in the alkali-basalt series of Chaine des Puys, Massif Central, France. Geochimica et Cosmochimica Acta, v.45, p.1997-2016.

VORMA, A. , 1976.
The petrology of rapakivi granites with special reference to the Laitila massif, southwest Finland. Geological Survey of Finland, Bulletin 285, 98 pp.

WAGENBAUER, H.A. , 1988.
Report of the geochemical laboratory for 1988. Newfoundland Dept.
Mines and Energy, Mineral Development Division, Report of Activities
for 1988, p.123-124.

WAGENBAUER, H.A., RILEY, C.A., and DAWE, G. , 1983.
Geochemical laboratory report. Newfoundland Dept. Mines and Energy,
Mineral Development Division, Report 83-1, p.133-137.

WALL, W.J., CLEMENS, J.D. and CLARKE, D.B. , 1987.
Models for granitoid evolution and source compositions. Journal of
Geology, v.95, p.731-749.

WALRAVEN, F. KLEEMAN, G.J. and ALLSOPP, H.L. , 1986.
Disturbance of trace element and isotopic systems and its bearing on
mineralization in acid rocks of the Bushveld Complex, South Africa.
In: High Heat Production Granites. Institute of Mining and
Metallurgy, Conference Proceedings, St.Austell, U.K., September,
1985, p.393-408.

WANLESS, R.K. and LOVERIDGE, W.D. , 1972.
Rubidium-strontium isotopic studies, report 1. Geological Survey of
Canada, Paper 72-23, p.57-59.

WANLESS, R.K., STEVENS, R.D., LACHANCE, G.R. and DELABIO, R.N. , 1970.
Age determinations and geological studies, K-Ar isotopic ages,
Report 9. Geological Survey of Canada, Paper 69-2A, p.73-74.

WARDLE, R.J. , 1984.
Geological fieldwork in the lower Proterozoic Aillik Group, eastern
Labrador. Newfoundland Dept. Mines and Energy, Mineral Development
Division, Report of activities for 1984, p.14-18.

WARDLE, R.J. and BAILEY, D.G. , 1981.
Early Proterozoic sequences in Labrador. In: Campbell, F.H.A. (ed.):
Proterozoic Basins of Canada. Geological Survey of Canada, Special
Paper 81-10, p.331-359.

WARDLE, R.J. AND Staff, Labrador Section. , 1982.
The Trans-Labrador batholith: A major pre-Grenvillian feature of the
eastern Grenville Province. Ottawa-Carleton Centre for Geoscience
Studies. Grenville Workshop, 1982, Program with abstracts. p.11.

WARDLE, R.J. and WILTON, D.H.C. , 1984.
Reconnaissance sampling for precious metals in the Kaipokok Bay -
Big River area, Labrador. Newfoundland Dept. Mines and Energy,
Mineral Development Division, Open File Report LAB(1679), 17 pp.

WARDLE, R.J., RIVERS, T., GOWER, C.F., NUNN, G.A.G. and THOMAS, A. ,
1986.
The northeastern Grenville Province : New insights. In: Moore et
al., 1986 (Eds). The Grenville Province. Geological Association of
Canada, Special Paper 31, p.13-29.

WARDLE, R.J., RYAN, B., NUNN, G.A. and MENGEL, F., in press.
Labrador segment of the Trans-Hudson Orogen: Crustal development
through oblique convergence and collision. Geological Association of
Canada. Special paper on the evolution of the Trans-Hudson Orogen.

WATSON, E.B. , 1982.
Zircon saturation in felsic liquids: Experimental results and
applications to trace element geochemistry. Contributions to
Mineralogy and Petrology, v.70, p. 407-419.

WHALEN, J.B., CURRIE, K.L. and CHAPPELL, B.W. , 1987.
A-type granites : geochemical characteristics, discrimination and petrogenesis. Contributions to Mineralogy and Petrology, v.95, p.407-419.

WHALEN, J.B., CURRIE, K.L. and CHAPPELL, B.W. , 1987b.
A-type granites: descriptive and geochemical data. Geological Survey of Canada, Open File Report 1411, 33 pp.

WHITE, A.J. and CHAPPELL, B.W. , 1977.
Ultrametamorphism and granitoid genesis. Tectonophysics, v.43, 7-22.

WHITE, A.J. and CHAPPELL, B.W. , 1983.
Granitoid types and their distribution in the Lachlan Fold Belt, southeastern Australia. In: Roddick, J.A.(ed.). Circum-Pacific Plutonic Terranes. Geological Society of America, memoir 159, p.21-34.

WHITE, M.V.W. , 1976.
A petrological study of acid volcanic rocks of the Aillik series, Labrador. Unpublished M.Sc. Thesis, McGill University, Montreal, 92 pp.

WHITE, M.V and MARTIN, R.F. , 1980.
The metasomatic changes that accompany mineralization in the non-orogenic rhyolites of the upper Aillik Group, Labrador. Canadian Mineralogist, v.18, p.459-479.

WHITE, W.M., and PATCHETT, P.J. , 1984.
Hf-Nd-Sr isotopes and incompatible element abundances in island arcs: implications for magma origins and crust-mantle evolution. Earth and Planetary Science Letters, v.67, p. 167-185.

WHITNEY, J.A. , 1988.
The origin of granite : The role and source of water in the evolution of granitic magmas. Bulletin of the Geological Society of America, v.100, p.1886-1897.

WILLIAMS, H., DICKSON, W.L., CURRIE, K.L., HAYES, J.P. and TUACH, J. , 1989.
Preliminary report on classification of Newfoundland granitic rocks and their relations to tectonostratigraphic zones and lower crustal blocks. Geological Survey of Canada, Current Research, Paper 89-1B, p.47-53.

WILSON, M.R., HAMILTON, P.J., FALLICK, A., AFTALION, M. and MICHARD, A. , 1985.
Granites and Early Proterozoic crustal evolution in Sweden: Evidence from Sm-Nd, U-Pb and O isotope systematics. Earth and Planetary Science Letters, v.72, p.376-388.

WILTON, D.H. and WARDLE, R.J. , 1987.
Two contrasting granophile and non-granophile metallogenic styles in the Early Proterozoic Upper Aillik Group, Central Mineral Belt, Labrador. Mineralium Deposita, v.22, p. 198-206.

WILTON, D.H.C., MACDOUGALL, C.M. and MACKENZIE, L.M. , 1986.
Final report on 1985 field work in the Central Mineral Belt of Labrador. Geological Survey of Canada, unpublished internal report, 98 pp.

WILTON, D.H.C. , MACDOUGALL, C.S., MACKENZIE, L.M. and NORTH, J.W. , 1987.
Final report on 1986 field work in the Central Mineral Belt of Labrador. Geological Survey of Canada, unpublished internal report, 121 pp.

- 496 -

WINDLEY, B.F. , 1977.
The Evolving Continents. Wiley, London. 385 pp.

WINDLEY, B.F. , 1983.
A tectonic review of the Proterozoic. In: Medaris,L.G. et al.(eds).
Proterozoic Geology. Geological Society Of America, Memoir 161,
p.1-11.

WINDRIM, D.P., McCULLOCH, M.T., CHAPPELL, B.W. and CAMERON, W.E. ,
1984.
Nd and Sr isotopes and REE in central Australian sapphirine
granulites: a case study of rare earth element mobility. Earth and
Planetary Science Letters, v.70, p.27-41.

WOODEN, J.L. and MUELLER, P.A. , 1988.
Pb, Sr and Nd isotopic compositions of a suite of Late Archean
igneous rocks, eastern Beartooth Mountains. Implications for
crust-mantle evolution. Earth and Planetary Science Letters, v.87,
p.59-72.

WRIGHT, A.E. and BOWES, D.R. , 1979.
Geochemistry of the appinite suite. In: Harris, A.L. et al. (eds.).
The Caledonides of the British Isles - Reviewed. Geological Society
Special Publication 8, p.699-704.

WYBORN, L.A. , 1988.
Petrology, geochemistry and origin of a major Australian 1880 - 1840
Ma felsic volcano-plutonic suite: A model for intracontinental
felsic magma generation. Precambrian Research, v.41, p.37-60.

WYBORN, L.A., PAGE, R.W., and PARKER, A.J. , 1987.
Geochemical and geochronological signatures in Australian
Proterozoic igneous rocks. In: Pharoah et al., (Eds.): Geochemistry
and Mineralization Of Proterozoic Volcanic Suites. Geological
Society Special Publication 33, p.377-394.

WYLLIE, P.J. , 1964.
Sources of granitoid magmas at convergent plate boundaries. Physics
of the Earth and Planetary Interiors, v.35, p.12-18.

YORK, D. , 1969.
Least squares fitting of a straight line with correlated errors.
Canadian Journal of Earth Sciences, v.5, p.320-324.

APPENDICES

APPENDIX A : METHODS AND PROCEDURES

A1. SAMPLE COLLECTION AND PREPARATION

Site Selection : The regional sampling program used
preselected sample sites (after Dickson, 1983), based on a
2 x 2 km grid cell network constructed from the Universal
Transverse Mercator (UTM) grid superimposed on National
Topographic System (NTS) 1:50,000 scale maps. Each cell was
subdivided into 16 sub-cells, one of which was selected on
a random basis for the sample site. Where a 2 x 2 km grid
cell straddled a geological contact indicated on existing
maps, sites were selected on both sides of the contact.
Follow-up sampling employed a similar method, but used 1 x
1 km primary cells.

Samples were collected as close as possible to the
preselected site, subject to outcrop availability and
topography. If outcrops contained more than one rock type,
both were noted and sampled. Sites for "geological" samples
collected during mapping were chosen on the basis of
lithology or field relationships, as is normal in mapping.

Field Procedures : Weathered material was removed and
discarded on outcrop, and 2 to 5 kg of fresh material was
reduced to fragments small enough for direct input to the
jaw crusher (< 5 cm maximum dimension). Material for hand
samples and thin sections was set aside. About half

the samples were thin-sectioned, and most were slabbed, etched with HF, and stained for K-feldspar with a saturated sodium dichromate solution. This turns K-feldspar yellow, and alters plagioclase to a white colour. Quartz is unaffected. All hand samples depicted in plates have been processed in this manner.

Sample Processing : All samples were processed at the Department of Mines laboratory in St.John's. Each was reduced to a fine gravel using a jaw crusher, which was cleaned between samples. About 20-30 grams of this material was reduced to powder using a ceramic disk and ring grinder (to minimize contamination by tungsten) an .tored in a clean medicine vial. The ceramic grinder was cleaned between runs with pure SiO_2 sand, distilled water and acetone.

A2. MAJOR AND TRACE ELEMENT ANALYSIS PROCEDURES

A2.1 Assessment of Geochemical Analysis Program

Precision : Precision of analysis was assessed using blind duplicates. At the Department of Mines laboratory, 1 analysis in 20 was a duplicate, split prior to grinding. "Precision" is defined as :

$$\text{PRECISION } (\pm \%) = 100 \times \frac{\text{absolute value } (V_1 - V_2)}{\text{mean value of } (V_1, V_2)}$$

(V_1 and V_2 are duplicate determinations of a sample).

At low abundance levels, precision is worse (i.e., ± a
higher percentage) than at high values. Mean precision is
thus strongly influenced by outlying values at or near
detection limits, and the median (50th percentile) value is
preferred here as an assessment of "average" precision in
analysis.

Detection Limit : Detection limits quoted for the
Department of Mines laboratory are concentration values at
which precision is approximately ± 100%. These are based on
blind duplicates measured over several years from all rock
types (Wagenbauer et al., 1983; Wagenbauer, 1988).

Accuracy : At the Department of Mines laboratory, 1
sample in 20 is either an internal or international
standard. Repeated determinations conducted during this
project were compared with recommended values quoted by
Abbey (1979, 1983). Recommended values for internal
standards are based on measurements over several years by
different methods.

A2.2 Department of Mines Analysis Program

Laboratory Procedures

Laboratory procedures at the Department of Mines
laboratory are described in detail by Wagenbauer et al.
(1983). About 0.1 g of sample was fused with lithium
metaborate and taken into solution via HCl-HF digestion for
major element and Zr analysis.

About 1 g of sample was taken into solution via a
HF-HCl-HClO$_4$ digestion for trace element analysis
.

Variable	Lab.	Analytical Method	Detection Limit	Mean Value	Range	Number of Analyses*	Number of Duplicates	PRECISION (+/- %) Mean	Median
Oxide (wt%)									
SiO2	N.D.M	AAS	0.07	67.42	39.25 - 88.45	1489	73	0.57%	0.38%
TiO2	N.D.M	AAS	0.01	0.48	0.01 - 2.77	1489	73	8.37%	4.35%
Al2O3	N.D.M	AAS	0.01	14.53	4.60 - 25.40	1489	73	1.06%	0.87%
Fe2O3	N.D.M	AAS	0.01	1.45	0.00 - 27.39	1489	73	10.39%	6.54%
FeO	N.D.M	Titration	0.01	2.32	0.01 - 14.04	1481	73	9.16%	3.96%
MnO	N.D.M	AAS	0.01	0.08	0.01 - 0.45	1489	73	5.92%	0.00%
MgO	N.D.M	AAS	0.01	1.35	0.01 - 28.02	1489	73	9.69%	2.30%
CaO	N.D.M	AAS	0.01	2.44	0.01 - 16.20	1489	73	4.17%	1.46%
Na2O	N.D.M	AAS	0.01	4.10	0.15 - 10.90	1489	73	1.45%	0.79%
K2O	N.D.M	AAS	0.01	4.52	0.06 - 12.06	1489	73	4.22%	1.01%
P2O5	N.D.M	AAS	0.01	0.13	0.01 - 2.26	1489	73	12.86%	4.65%
LOI	N.D.M	Oven Drying	n/a	0.71	0.02 - 6.02	1485	73	13.70%	7.02%
Element (ppm)									
Li	N.D.M	AAS	5	21.0	1 - 286	1491	73	13.29%	8.22%
F	N.D.M	ISE	30	866.5	11 - 9968	1487	52	15.51%	9.38%
Sc	Becquerel	INAA	0.1	4.5	0.2 - 75.0	529	23	22.14%	9.52%
V	N.D.M	AAS	20	49.7	1 - 705	1494	73	25.52%	15.40%
Cr	N.D.M	AAS	1	34.3	1 - 1840	1491	73	20.39%	5.70%
Ni	N.D.M	AAS	1	10.3	1 - 823	1491	73	18.86%	0.00%
Cu	N.D.M	AAS	1	15.1	1 - 809	1491	73	7.41%	0.00%
Zn	N.D.M	AAS	1	70.0	1 - 527	1491	73	3.69%	2.53%
Ga	N.D.M	ICP-ES	1	15.9	1 - 71	1490	74	5.26%	4.44%
Rb	N.D.M	AAS	5	144.5	1 - 1250	1491	73	6.69%	2.84%
Sr	N.D.M	AAS	2	250.8	2 - 1930	1490	73	5.76%	1.90%
Y	N.D.M	ICP-ES	1	40.9	2 - 381	1490	74	3.90%	3.45%
Zr	N.D.M	ICP-ES	1	229.4	11 - 2880	1490	74	6.24%	4.44%
Nb	N.D.M	ICP-ES	1	19.0	1 - 249	1490	74	7.00%	3.64%
Mo	N.D.M	AAS	2	8.3	1 - 4752	1491	73	19.60%	0.00%
Sn	B-C	XRF-ES	1	4.4	1 - 116	529	23	73.29%	66.67%
Cs	Becquerel	NAA	0.5	2.42	0.5 - 32.0	529	23	26.41%	5.97%
Ba	N.D.M	AAS	30	690.8	6 - 5140	1491	73	9.14%	3.13%
La	N.D.M	ICP-ES	1	59.3	1 - 1312	1490	74	5.26%	4.65%
Ce	N.D.M	ICP-ES	2	119.7	1 - 2226	1490	74	5.46%	4.06%
Sm	Becquerel	NAA	0.1	11.3	0.1 - 113.0	529	23	7.44%	4.26%
Yb	Becquerel	NAA	0.5	5.6	3.0 - 36.0	529	23	14.85%	4.00%
Hf	Becquerel	NAA	1.0	11.5	1.0 - 150.0	529	23	24.76%	12.24%
Pb	N.D.M	AAS	2	20.1	1 - 2900	1491	73	6.19%	5.13%
Th	N.D.M	ICP-ES	1	13.3	1 - 163	1490	74	27.85%	13.33%
U	N.A.S	NAA	0.2	4.5	0.1 - 74.7	1491	52	9.20%	6.45%

ANALYSTS :
N.D.M --- Newfoundland Department of Mines, St. John's.
N.A.S --- Nuclear Activation Services, Hamilton.
Becquerel --- Becquerel Laboratories, Mississauga
B-C --- Bondar-Clegg and Co. Ltd , Ottawa.

ANALYTICAL METHODS :
AAS --- Atomic Absorption Spectrophotometry
ICP-ES --- Inductively-Coupled Plasma Emission Spectrometry
INAA --- Instrumental Neutron Activation Analysis
ISE --- Ion-Selective Electrode
XRF-ES --- X-Ray Fluorescence Emission Spectrometry

Table A.1. Abundance levels, detection limits and estimates of precision for major and trace elements determined at, or via, the Department of Mines laboratory.

(excluding Zr and F). About 0.25 α of sample was fused with
Na_2CO_3 - KNO_3 flux, and taken into solution with
citric acid for fluorine analysis. Loss on ignition (LOI)
was determined after heating a portion of the sample powder
to $1000^{\circ}C$ in a muffle furnace. Separate aliquots of
sample powder were weighed and sent out for external
analysis of selected trace elements (see below).

Analytical Methods

Major Elements : These were determined by atomic
absorption spectrophotometry (AAS), using standard
solutions supplied by CANLAB Ltd. Ferrous iron was
determined by addition of vanadium, followed by titration
using standard potassium dichromate solutions. Details are
supplied by Wagenbauer et al.(1983)

Li, V, Cr, Ni, Cu, Zn, Rb, Sr, Ba and Pb : These
elements were determined by AAS, as described above.
Details of procedures are supplied by Wagenbauer et
al.(1983).

Ga, Y, Zr, Nb, La, Ce and Th : These elements were
determined by inductively-coupled plasma emission
spectroscopy (ICP-ES) using an ARL 3520 sequential
spectrometer, and standard solutions supplied by SPEX
Industries Ltd. Note that Zr was analyzed on solutions from
the major element fusion.

Fluorine : This element was determined via
ion-selective electrode (ISE) analysis using a digital ion-
analyzer, and standard solutions supplied by CANLAB Ltd.

Uranium : This element was determined externally by Nuclear Activation Services Ltd, via neutron activation analysis (NAA). About 2 g of each sample was irradiated.

Sc, Cs, Sm, Yb and Hf : These elements were determined externally in selected samples by Becquerel Laboratories, using standard NAA methods. This forms part of the "gold+33" commercial package. About 10 g of each sample was irradiated. A range of other elements determined via this method are not reported here because of low and imprecise abundances, or because they duplicate data obtained by other methods.

Tin : This element was determined in selected samples by Bondar-Clegg Incorporated, via wavelength-dispersive X-Ray fluorescence (XRF) analysis, on a pellet containing about 5 g of sample.

Precision and Detection Limits

Table A.1 lists relevant information for all elements determined at or via the Department of Mines laboratory. Detection limits for Sn (1 ppm) are those quoted by the analyst; all others are based on multiple determinations over several years (see above). Detection limits for Sc, Cs, Sm, Yb and Hf are based on a survey by Davenport (pers. comm., 1988) using lake sediment samples, and are generally higher than limits quoted by the analyst.

The median (50th percentile) value is the preferred estimate of analytical precision. For elements with generally low abundances (e.g. V), poor mean precision results from many determinations at or near detection

Table A.2. Mean analyses of the international standards MRG-1,
SY-2 and SP-1 by the Department of Mines laboratory, compared to
recommended values of Abbey (1979, 1983).

STD:	SY-2			MRG-1			GSP-1		

MAJOR ELEMENTS (wt% Oxide)

	Mean	S.D.	R.V.	Mean	S.D.	R.V.	Mean	S.D.	R.V.
	n=3			n=3			n=6		
SiO2	60.02	0.72	60.10	39.02	0.25	39.32	66.83	0.56	67.32
TiO2	0.14	0.01	0.14	3.89	0.05	3.69	0.66	0.02	0.66
Al2O3	12.20	0.13	12.20	8.54	0.04	8.50	14.97	0.13	15.28
Fe2O3t	6.36	0.07	6.28	17.81	0.30	17.82	4.27	0.06	4.3
MnO	0.32	0.01	0.32	0.18	0.00	0.17	0.05	0	0.04
MgO	2.72	0.02	2.70	13.89	0.12	13.49	0.97	0.01	0.97
CaO	8.04	0.04	7.98	14.75	0.04	14.77	1.98	0.04	2.03
Na2O	4.29	0.05	4.34	0.71	0.00	0.71	2.79	0.03	2.81
K2O	4.47	0.06	4.48	0.17	0.00	0.18	5.58	0.11	5.51
P2O5	0.43	0.03	0.43	0.06	0.00	0.06	0.27	0.03	0.28

TRACE ELEMENTS BY AAS (ppm)

N	n=18			n=18					
Li	90.2	7.6	93.0	10.4	3.9	4			
V	61.4	10.6	52.0	539.9	19.5	520			
Cr	7.2	1.4	10.0	327.3	21.2	420			
Ni	4.6	0.9	10.0	145.3	5.5	200			
Cu	5.2	0.6	5.0	109.1	4	136			
Zn	264.3	50.3	250.0	193.4	7	185			
Rb	210.0	21.3	220.0	12.7	4	8			
Sr	274.5	8.9	275.0	260.5	14.6	260			
Mo	3.3	0.4	3.0	4.7	1.2	5.0			
Ba	460.4	31.3	460.0	83.5	16	50			
Pb	76.6	2.7	86.0	10	0	10			

TRACE ELEMENTS BY ICP-ES (ppm)

	n=18			n=18					
Ga	23.9	1.4	28.0	24.5	1.2	18.0			
Y	129.7	4.6	130.0	10.5	0.8	16.0			
Zr	313.8	18.9	280.0	121.3	17.3	105.0			
Nb	25.6	1.0	23.0	13.5	0.8	20.0			
La	69.4	3.0	88.0	17.5	5.7	10.0			
Ce	164.8	5.7	210.0	38.7	3.0	25.0			
Th	383.4	27.0	380.0	1.0	0.2	1.0			

TRACE ELEMENTS BY NAA (ppm)

	n=12			n=9					
Sc	6.0	0.5	7.0	53.8	4.1	48.0			
Cs	2.7	0.3	2.3	0.8	0.2	0.6			
Sm	8.6	2.1	15.0	4.9	0.3	5.0			
Yb	20.4	4.0	17.0	2.2	2.0	1.0			
Hf	8.3	0.8	8.0	3.8	0.5	3.0			

OTHER TRACE ELEMENTS (ppm)

Sn	4.6	2.2	4.0	1	0	3.2			

R.V. = Recommended Value (Abbey, 1979; 1983)   S.D. = Standard Deviation

limit; note the large differences between mean and median
precision for Cr, Ni and Mo. In the case of Sn, data are
capable only of resolving anomalous samples. Apparent poor
precision for Th is mostly induced by mafic rocks
containing only 1-2 ppm Th; if these are excluded,
precision is closer to ± 6%.

Accuracy

Table A.2 lists mean analyses and standard deviations
for the international standards MRG-1, SY-2 and GSP-1,
compared to the recommended values listed by Abbey
(1979,1983),. There is good agreement for most elements.
Notable exceptions include Ni and Ce, which are somewhat
lower than recommended values for MRG-1 and SY-2
respectively. However, in the case of Ce, ICP-ES data for
SY-2 are in close agreement with the ICP-MS data from MUN
(Table A.3).

Accuracy for U and F was monitored only by internal
Department of Mines standards. Data for these are in good
agreement with compilations of previous results
(Wagenbauer, pers.comm., 1989), and are within their
respective precision envelopes.

A2.3 Memorial University Analysis Program

Selected samples were analyzed for REE and a range of
other trace elements at Memorial University. About 0.5 g of
sample w s digested in $HF-HNO_3$ in sealed teflon bombs to
ensure di solution of zircon. A subset of the samples were
also processed using NaOH fusion methods followed by HNO_3
digestion. This method is now standard for REE analysis at
MUN; however, in the case of TLGB samples, there was
little difference between results from the two methods.

Table A.3. Mean trace element analysis of SY-2 by ICP-MS analysis at Memorial University, compared to recommended values of Abbey (1979, 1983).

Element	N	Mean	S.D.	SY-2 Recommended Value	Quoted Detection Limit
(ppm)					
Li	5	90.1	5.1	93.0	0.3
Be	2	23.0	1.4	23.0	0.4
Sc	2	6.7	0.0	7.0	1.2
Rb	5	219.8	7.0	220.0	0.1
Sr	5	268.8	12.2	275.0	0.2
Y	6	111.7	5.1	130.0	0.1
Zr	6	251.3	11.4	280.0	0.2
Nb	3	25.1	1.6	23.0	0.1
Mo	2	0.8	0.1	3.0	0.1
Cs	5	2.7	0.0	2.3	0.1
Ba	7	444.4	18.5	460.0	0.1
La	7	67.6	1.5	88.0	0.1
Ce	7	154.0	3.2	210.0	0.1
Pr	7	18.9	0.6	21.0	0.1
Nd	7	70.9	1.8	75.0	0.7
Sm	7	15.1	0.6	15.0	0.2
Eu	7	2.3	0.1	2.7	0.1
Gd	7	14.8	1.1	17.0	0.1
Tb	7	2.8	0.1	2.5	0.1
Dy	7	19.1	0.7	20.5	0.1
Ho	7	4.3	0.2	5.0	0.1
Er	7	14.5	0.9	14.0	0.1
Tm	7	2.3	0.2	2.3	0.1
Yb	7	16.6	1.3	17.0	0.1
Lu	7	2.8	0.3	3.0	0.1
Hf	6	8.5	0.5	8.0	0.1
Ta	3	0.6	0.4	1.2	0.1
Tl	5	1.5	0.1	1.4	0.2
Pb	5	68.1	12.4	86.0	0.1
Bi	5	0.1	0.0	0.1	0.1
Th	7	365.0	56.5	380.0	0.1
U	5	292.3	21.7	290.0	0.1

Recommended values after Abbey (1979,1983), or accepted MUN values in the case of Tl, Ta and Bi.

Analysis was conducted on a SCIEX inductively-coupled plasma mass spectrometer (ICP-MS). Details of analytical techniques and instrument specifications are provided by Longerich et al. (in prep.). Precision is estimated at ± 6% or better for most elements (based on duplicate analyses over several years), with the exception of Be, Sc, Ta and Li, for which it may be as poor as ± 10%, particularly at low levels (Longerich et al., in prep.).

The results of repeated ICP-MS analyses of SY-2 are listed in Table A.3. For most elements, there is good agreement with the Department of Mines laboratory, even where measured values are somewhat lower than recommended for (e.g. Ce). Detection limits quoted in Table A.3 are based on mean background + 3 σ, and are probably underestimates of true limits of analytical precision.

A3. STRONTIUM ISOTOPIC ANALYSIS PROCEDURES

A3.1 Laboratory Procedures

Samples were prepared for measurement of Rb/Sr ratios at the Department of Mines laboratory, as described above for trace elements. For Sr isotopic composition analysis, 0.1 to 0.2 g of sample was taken into solution via $HF-HNO_3$ digestion, and converted to chloride. Sr was separated by standard ion-exchange procedures using amberlite resin and chloride solutions. Each sample was passed through ion-exchange columns twice to ensure removal of all Rb. Sr separates were stored as chloride solutions. Sr separations were performed by Pamela King at Memorial University.

A3.2 Determination of $^{87}Rb/^{86}Sr$

$^{87}Rb/^{86}Sr$ ratios were determined at the Department of Mines laboratory by repeated AAS analysis of each sample for Rb and Sr. Precision was assessed by calculating the mean and standard error for each sample, based on 10 - 20 repeated determinations, and by running several samples twice (Table A.4). Calculated $^{87}Rb/^{86}Sr$ ratios are corrected for $^{87}Sr/^{86}Sr$ ratios measured by mass spectrometry. The precision is poorest at low Rb contents, but 2 σ within-run uncertainties are ± 2% or better for most samples. Duplicate determinations suggest that 2 σ within-run uncertainties approximate or underestimate true 1 σ analytical uncertainty, and 2 σ within-run values were therefore used in isochron regression (Chapter 8).

Table A.4. Duplicate determinations of $^{87}Rb/^{86}Sr$ ratios by repeated AAS analyses at the Department of Mines laboratory. Errors are 2 σ.

Sample Number	Determination 1	Determination 2
0241041	0.945 +/- 10	0.895 +/- 15
0249030	0.314 +/- 9	0.351 +/- 4
0241391	12.542 +/- 198	11.660 +/- 166
0241173	0.032 +/- 5	0.021 +/- 5
0241538	3.081 +/- 73	3.232 +/- 80

NOTE: All errors are x 10^3

A3.3 Determination of $^{87}Sr/^{86}Sr$

Mass Spectrometry

$^{87}Sr/^{86}Sr$ ratios were determined by thermal ionization mass spectrometry, using the venerable Vacuum

Generators Micromass 30B single-collector instrument known (affectionately ?) as "Miss Piggy". Most samples were run by the author; a few were run in early stages of the project by Pamela King. Samples were loaded as chloride on single W filaments, and coated with tantalum fluoride. During runs, all measured ratios were normalized to a $^{86}Sr/^{88}Sr$ ratio of 0.1194.

Samples were run under automatic control for periods ranging from 4 to 24 hours, corresponding to 40 to 250 cycles of data acquisition, organized into blocks of 20 or 30 cycles. Samples with low Sr contents are difficult to run, as they do not generally last long enough to produce high-precision data. Accordingly, samples with $^{87}Sr/^{86}Sr > 1.0$ were run using a gain of x10 on the Faraday cup detector, and an ion beam intensity measurement of 2 - 3 volts. All other samples were run using a gain of x1, and an ion beam intensity of 0.8 - 1.0 volts.

The control program automatically rejects observations that fail a Q-test, and blocks of data exhibiting poor internal precision were not included in final calculations. Data were windsorized a maximum of five times to exclude outlying observations that were retained by the program.

Precision and Accuracy

Three samples were repeated to check between-run precision (Table A.5). Results suggest that 2 σ within-run errors are a good approximation to true 1 σ uncertainties, and these values were thus employed in isochron regression (Chapter 8).

Accuracy was assessed by running the Sr-carbonate standard NBS-987, at an average frequency of 1 standard for every six samples. Results for NBS-987 obtained during this project are shown in Table A.6. The mean value is slightly

higher than the recommended value of 0.710260 ± 20. Data
have not been normalized to this value because the
uncertainty associated with most TLGB samples (particularly
those with high Rb/Sr) is equal to or greater than the
discrepancy in standard determinations.

Table A.5. Duplicate determinations of $^{87}Sr/^{86}Sr$ ratios by
thermal ionization mass spectrometry at Memorial University.
Errors are 2 σ.

Sample Number	Determination 1	Determination 2
0241538	0.779743 +/- 518	0.780360 +/- 64
0249030	0.711421 +/- 108	0.711398 +/- 106
0241391	1.012539 +/- 296	1.012098 +/- 349

NOTE: All errors are x 10^6

Table A.6. Determinations and mean value of the Sr-carbonate
isotopic standard NBS-987 during the course of this project.

Date	Value +/-	2 σ
ACCEPTED VALUE	0.710260 +/-	20
September 1987	0.710421 +/-	56
October 1987	0.710344 +/-	66
January 1988 *	0.710581 +/-	88
January 1988	0.710350 +/-	78
January 1989	0.710336 +/-	54
February 1989	0.710300 +/-	39
March 1989	0.710376 +/-	55
March 1989	0.710389 +/-	66
Mean Value	0.710387 +/-	57
Mean Value Excluding *	0.710359 +/-	23

NOTE: All errors are x 10^6

NOTE : Quoted errors on mean values are standard
errors of the mean, i.e. 2 standard deviations
divided by square root of number of observations.

A4. NEODYMIUM ISOTOPE ANALYSIS PROCEDURES

A4.1 Laboratory Procedures

Samples for determination of $^{147}Sm/^{144}Nd$ by ICP-MS were processed using the NaOH fusion method described above for trace element (MUN) determinations.

For Nd isotopic analysis, 0.1 to 0.2 g of sample was taken into solution via HF-HNO$_3$ digestion in teflon bombs for 1 week under clean-lab conditions. After dissolution, a 1 ml aliquot of each sample was spiked with 20 microlitres of a mixed ^{150}Nd - ^{147}Sm solution (MUN spike #1). This isotope dilution (ID) split, and the unspiked isotopic composition (IC) split, were then processed via a three stage ion-exchange procedure to isolate Nd and Sm.

Stage 1 employs amberlite resin and chloride solutions, and separates the REE and Ba from all other elements. Stage 2 employs amberlite resin and nitrate solutions, and separates the REE from Ba. Stage 3 employs teflon beads coated with di-2-ethylhexyl orthophosphoric acid, and chloride solutions, and separates Nd (IC split) and Nd and Sm (ID split) from other REE. Samples were stored as chloride or nitrate solutions. All ion-exchange chemistry was conducted under clean-lab conditions in a positive pressure hood. Twenty samples were processed initially by Patricia Horan, and the remainder of the laboratory work was conducted by the author.

Nd and Sm ID separates were prepared fully for about one-third of the samples to assess the accuracy of high-precision ICP-MS $^{147}Sm/^{144}Nd$ determinations used in this study (see below).

A4.2 Determination of $^{147}Sm/^{144}Nd$

$^{147}Sm/^{144}Nd$ values were mostly determined by high-precision ICP-MS. This employs a longer counting period (180 seconds) for each element compared to the ICP-MS multi-element analysis (10 seconds), and is therefore more precise (S.Jackson, pers.comm., 1989). Each sample was run twice, and results averaged. Standards used in calibration were prepared from pure Nd and Sm metals provided by AMES Ltd. Replicate determinations suggest that the average 2 σ precision for $^{147}Sm/^{144}Nd$ at Sm and Nd concentrations typical of TLGB granitoid rocks is ± 0.5 % or better (H.Longerich, pers.comm., 1988). This value has been used to estimate errors in calculation of ϵ_{Nd} and T_{CHUR} (Chapter 8).

A comparison of ICP-MS data with more precise ID data obtained by thermal ionization mass spectrometry (see below) shows a generally close correspondence. All except three ID measurements lie within the ± 0.5% 2 σ error envelope of the ICP-MS measurements, and several have identical mean $^{147}Sm/^{144}Nd$ by both methods (Table A.7).

Table A.7. Comparison of $^{147}Sm/^{144}Nd$ ratios measured by high-precision ICP-MS methods and by Isotope Dilution (ID) techniques, using thermal ionization mass spectrometry.

Sample Number	147Sm/144Nd [Isotope Dilution]		147Sm/144Nd (ICP - MS)	
AKZ-2	0.0922 +/-	21	0.0930 +/-	47
AKZ-3	0.1033 +/-	3	0.1030 +/-	51
AKZ-4	0.0876 +/-	2	0.0872 +/-	44
AKZ-5	0.0924 +/-	46	0.0933 +/-	47
AKZ-6	0.1018 +/-	3	0.1025 +/-	51
AKZ-7	0.1005 +/-	2	0.0933 +/-	47
AKZ-8	0.1039 +/-	2	0.1021 +/-	51
AKZ-11	0.1100 +/-	5	0.1175 +/-.	59
AKZ-12	0.1105 +/-	9	0.1063 +/-	53
AKZ-13	0.1070 +/-	2	0.1068 +/-	53
AKZ-14	0.0910 +/-	. 4	0.0993 +/-	50
AKZ-15	0.1378 +/-	5	0.1395 +/-	70
GSZ-2	0.1116 +/-	9	0.1114 +/-	56

NOTE: All errors are x 10^4

A4.3 Determination of $^{143}Nd/^{144}Nd$

Mass Spectrometry

Samples were run on the same Micromass 30B instrument used for Sr isotopic analysis. Most were run by the author, except for six samples run by Dr.B.J.Fryer in early stages of the project. Samples were loaded as chloride or nitrate on Re side-filaments in a triple-filament assembly, and oxidized after coating with phosphoric acid. All measured ratios were normalized to a $^{146}Nd/^{144}Nd$ ratio of 0.7219. Samples were run under automatic control for periods ranging from 8 to 48 hours, corresponding to 90 to 550 cycles of data acquisition, organized into blocks of 30 cycles. Most were analyzed with a gain of x1 on the Faraday cup, and an ion beam intensity measurement of 0.8 to 1.1 volts. A few (Nd-poor) leucogranite samples were analyzed at a gain of x10 and an ion beam intensity of 2-3 volts, in order to extend their running times. Data reduction methods were identical to those used for Sr isotopic data. The limits for acceptance of a 30-cycle block of data were set at a 1 σ within-block uncertainty of 0.000100 or less. Using a more stringent limit (e.g. 0.000050) would improve the apparent precision of $^{143}Nd/^{144}Nd$ ratios considerably, but would almost certainly underestimate the true uncertainty of determinations.

Isotope dilution (ID) analysis employed similar procedures to measure $^{150}Nd/^{144}Nd$ (Nd ID) and $^{147}Sm/^{149}Sm$ (Sm ID) respectively. Molar concentrations of ^{147}Sm and ^{144}Nd were derived using a spreadsheet written by H.Longerich.

Precision and Accuracy

Between-run precision was assessed by repeating several sample determinations (Table A.8). Results for each duplicate pair compare well, and are identical within the respective 2 σ error envelopes. The 2 σ within-run uncertainties are thus regarded as a good approximation to true 2 σ analytical errors. Duplicate digestions were not performed.

Table A.8. Duplicate determinations of $^{143}Nd/^{144}Nd$ ratios by thermal ionization mass spectrometry at Memorial University. Errors are 2 σ.

Sample Number	Determination 1		Determination 2	
AKZ-6	0.511604 +/-	61	0.511515 +/-	85
AKZ-14	0.511188 +/-	29	0.511184 +/-	35
AKZ-3	0.511326 +/-	25	0.511296 +/-	40
AKZ-4	0.511606 +/-	51	0.510665 +/-	54
AKZ-20	0.511623 +/-	70	0.511648 +/-	63
AKZ-12	0.511640 +/-	47	0.511536 +/-	95

NOTE: All errors are x 10^6

Accuracy was assessed by replicate determinations of the LaJolla Nd isotope standard, at an average frequency of one standard for every six samples. Determinations over the course of this project are listed in Table A.9. The mean values are slightly higher than the recommended value of 0.511850, but compare well to the average MUN value. ϵ_{Nd} values would be reduced by ca. 0.8 ϵ units if all $^{143}Nd/^{144}Nd$ ratios were normalized to 0.511850, but contrasts among samples would remain unchanged.

Table A.9. Determinations and average value of the LaJolla Nd
isotopic standard during the course of this project.

Date	Value +/-	2 σ
ACCEPTED VALUE	0.511850	
MUN Average	0.511892 +/-	20
October 1987	0.511953 +/-	56
October 1987	0.511890 +/-	24
November 1987	0.511919 +/-	24
November 1987	0.511905 +/-	28
November 1987	0.511896 +/-	60
March 1988	0.511887 +/-	78
May 1988	0.511948 +/-	44
May 1988	0.511977 +/-	34
August 1988 *	0.512003 +/-	58
September 1988	0.511962 +/-	74
November 1988	0.511936 +/-	31
March 1989	0.511940 +/-	26
Mean Value	0.511935 +/-	20
Mean Value (Excluding *)	0.511928 +/-	17

NOTE : Quoted errors on mean values are standard
errors of the mean, i.e. 2 standard deviations
divided by the square root of number of observations.

NOTE: All errors are x 10^6

APPENDIX B: GEOCHEMICAL DATA LISTINGS

Major and Trace Element Data

Geochemical data employed in this thesis are presented in microfiche format. Data are organized into the five groupings represented by Chapters 3, 4, 5, 6 and 7, and into separate listings for major and trace element analyses. Within each category, data are sorted by map unit and sample number; a key to the variable MAP UNIT is provided on the first page of the microfiche listing. Note that regional, follow-up and geological sample populations are designated by sample numbering sequences, as follows :

0241000 - 0242999   Regional Samples (2 km grid),
0248000 - 0248999   Follow-Up Samples (1 km grid),
0249000 - 0249999   Geological Samples (no grid).

Locational information included with major element data includes National Topographic System (NTS) map sheet (variable NTS MAP) and Universal Transverse Mercator (UTM) grid coordinates in metres (variables EAST UTM and NORTH UTM). The lithology (variable ROCK TYPE) listed is the normative IUGS plutonic classification according to the method of Streckeisen and LeMaitre (1979).

ICP-MS Trace Element Data

ICP-MS trace element data are also listed in microfiche format. For locations of all these samples, see Figure 8.4. Coordinates for all 024.... series samples are also listed in the main data listing. Major element data for the AKZ- and GSZ- series samples were determined at the Department of Mines Laboratory, as described above.

UNABLE TO FILM MATERIAL ACCOMPANYING THIS THESIS (I.E. DISKETTE(S), SLIDES, MICROFICHE, ETC...).

PLEASE CONTACT THE UNIVERSITY LIBRARY.

INCAPABLE DE MICROFILMER LE MATERIEL QUI ACCOMPAGNE CETTE THESE (EX. DISQUETTES, DIAPOSITIVES, MICROFICHE (S), ETC...).

VEUILLEZ CONTACTER LA BIBLIOTHEQUE DE L'UNIVERSITE.

APPENDIX C : MISCELLANEOUS INFORMATION

Partition Coefficients

Table C.1 lists mineral/melt partition coefficients employed in modelling evolution of the Adlavik and Mount Benedict Intrusive Suites. Values for orthopyroxene (Opx) and amphibole (Hb) are from a compilation of basalt-related studies (Jenner, 1984), as are values for Y and V in all minerals. All others are from Villemant et al.(1981).

Chondrite Normalization Values

Values (Table C.2) are from Taylor and MacClennan (1985)

Note on Normative Calculations

Calculations were performed using computer programs developed by K.Parsons of the Department of Mines. CIPW norm calculations recalculate all data on an anhydrous basis, normalized to a 100% total. Calculation steps follow standard procedures, as described in igneous petrology texts. Mesonorm calculations are conducted according to the method of Barth (1955). H_2O contents are assumed to be given by loss-on-ignition (LOI) measurements, on the basis that hygroscopic water contents are negligable. Assumptions regarding mineral formulae correspond to those of Barth (1955). Iron is recalculated as FeO, and any excess Al_2O_3 is expressed as normative corundum.

It should be noted that, although Streckeisen and LeMaitre (1979) recommend mesonorms for their classification scheme, other studies (e.g., Bowden et al., 1984), and the author's own comparisons, indicate that results obtained from CIPW and mesonorm data differ only very slightly, except where rocks contain large amounts of biotite or muscovite.

Table C.1. Mineral-Melt partition coefficients employed in trace element modelling. see text for sources.

Mineral:	Plag.	K-fsp	Hb	Cpx	Opx	Ol	Bi	Fe-Ox
Element:								
U	0.04	0.1	0.54	0.05	0.005	0.04	0.13	0.14
Th	0.05	0.09	0.54	0.04	0.005	0.03	0.12	0.11
La	0.2	0.24	0.16	0.12	0.005	0.03	0.7	0.1
Y	0.03	0.015	1	0.5	0.2	0.01	1.06	0.001
Rb	0.13	0.3	0.25	0.04	0.02	0.04	1.9	0.001
Zr	0.13	0.27	0.5	0.27	0.03	0.06	2.5	0.001
Ba	0.56	3.6	0.31	0.04	0.013	0.03	10	0.001
Sr	2.7	10	0.57	0.16	0.016	0.02	0.7	0.001
V	0.08	0.5	4	1.5	0.3	0.09	23	30
Cr	0.08	0.6	3	5.3	10	2.8	5.4	5.3
Ni	0.04	0.5	7	2.5	4	34	1.3	5.5
Ti	0.05	0.05	1.5	1.07	0.1	0.005	13	12

Table C.2. Chondrite normalization values currently in use at Memorial University. Only values for Y and REE were employed here.

Li	2.4	La	0.376	Hf	0.179
Be	0.04	Ce	0.957	Ta	0.026
Sc	8.64	Pr	0.137	W	0.089
Rb	3.45	Nd	0.711	Tl	0.215
Sr	11.9	Sm	0.231	Pb	3.65
Y	2.25	Eu	0.087	Bi	0.167
Zr	5.54	Gd	0.306	Th	0.043
Nb	0.375	Tb	0.058	U	0.012
Mo	1.38	Dy	0.381		
Cs	0.279	Ho	0.085		
Ba	3.41	Er	0.249		
		Tm	0.036		
		Yb	0.248		
		Lu	0.038		

APPENDIX D : SUMMARY OF U-PB ZIRCON GEOCHRONOLOGICAL DATA

General Statement

This appendix briefly summarizes recent (unpublished) U-Pb zircon ages that are crucial in dividing the TLGB into Makkovikian and Labradorian assemblages.

This work was carried out by Drs. Tom Krogh and Urs Schärer (and their associates), at the Royal Ontario Museum (ROM) geochronology laboratory in Toronto, partly under contract to the Newfoundland Department of Mines, and partly from their personal interests in this project. These U-Pb zircon data are being prepared for full publication elsewhere (Krogh et al., in prep.). Note that any reference to these unpublished ages should be to Krogh et al. (in prep.), and <u>not</u> to this thesis. Note also that some mineral fractions (notably sphenes) have yet to be ana¹vzed, and that ages and error estimates may be subject to minor revisions. Data from the Big River and Stag Bay units, and final data from the Cape Strawberry Granite, were received too late for inclusion in the main body of the text, except as footnotes.

No attempt is made here to review the rigorous processing, grain selection, abrasion and mass spectrometry procedures routinely employed at ROM. These have most recently been described by Schärer et al.(1986).

Adlavik Intrusive Suite

A potassic, monzonitic variant of the dioritic unit of the Adlavik Intrusive Suite was sampled at the entrance to Adlavik Bay, from the 0249030 sample locality (Figure 8.4).
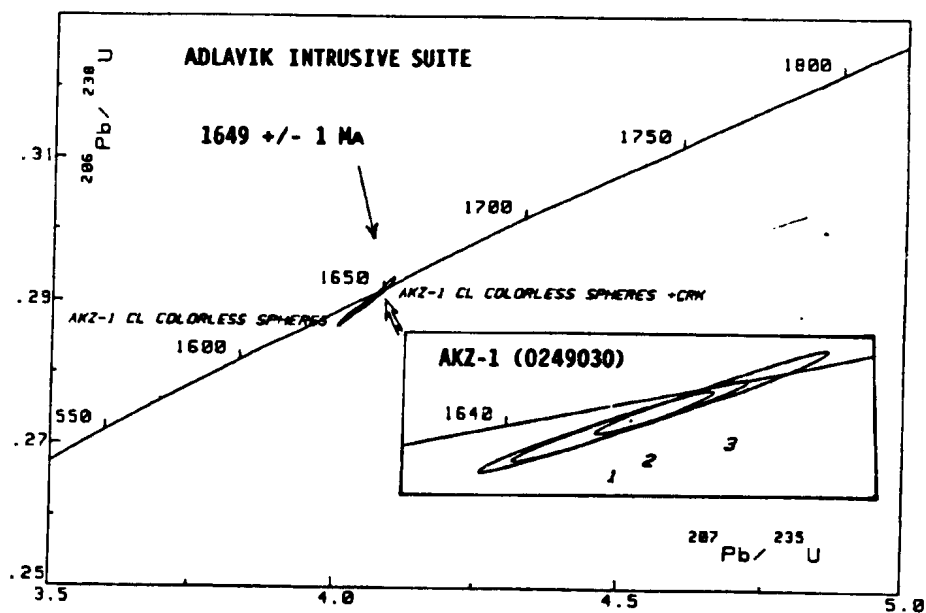
Figure D.1. $^{206}Pb/^{238}U$ – $^{207}Pb/^{235}U$ concordia diagram for the diorite unit of the Adlavik Intrusive Suite.
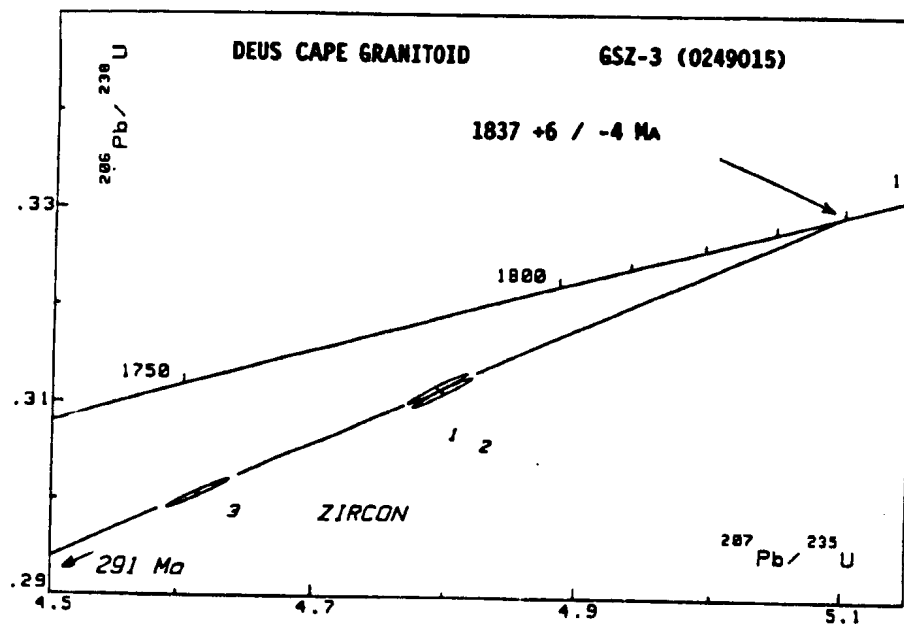
Figure D.2. $^{206}Pb/^{238}U$ – $^{207}Pb/^{235}U$ concordia diagram for the Deus Cape Granitoid.

Three abraded zircon fractions were analyzed in 1987; two
are concordant, and a third is about 1% discordant. Two
additional fractions analyzed in 1988 gave slightly
discordant results. A precise crystallization age of 1649 ±
1 Ma is indicated (Figure D.1), and the zircon population
appears simple.

Deus Cape Granitoid

A foliated, leucocratic granite was sampled south of
Deus Cape, from the 0249015 sample locality (Figure 8.4).
Three abraded fractions are from 5% to 8% discordant, and
define an age of 1837 +6 / -4 Ma (Figure D.2). A single
sphene analysis suggested a minimum age of ca. 1782 Ma (not
figured).

Numok Intrusive Suite

Two samples were collected. AKZ-5 (located in Figure
8.4) is a fayalite-bearing syenite from Kikkertavak (Numok)
Island. HSZ-1 is a foliated quartz monzonite that forms the
neosome to the western contact zone agmatite at Adlavik
Bay; this was sampled with the intention of providing a
maximum age for localized deformation here. HSZ-1 is
located about 1 km east of the 0249030 sample locality
(Figure 8.4).

AKZ-5 yielded colourless, euhedral, gem-quality zircons
that plot on concordia at 1801 ± 2 Ma (Figure D.3). The
zircon population appears to be simple. HSZ-1 yielded two
fractions that are 4% and 6% discordant along a line from
1800 Ma (concordia) to 1000 Ma (lower intercept). They
indicate a closely similar crystallization age to AKZ-5
(Figure D.3)
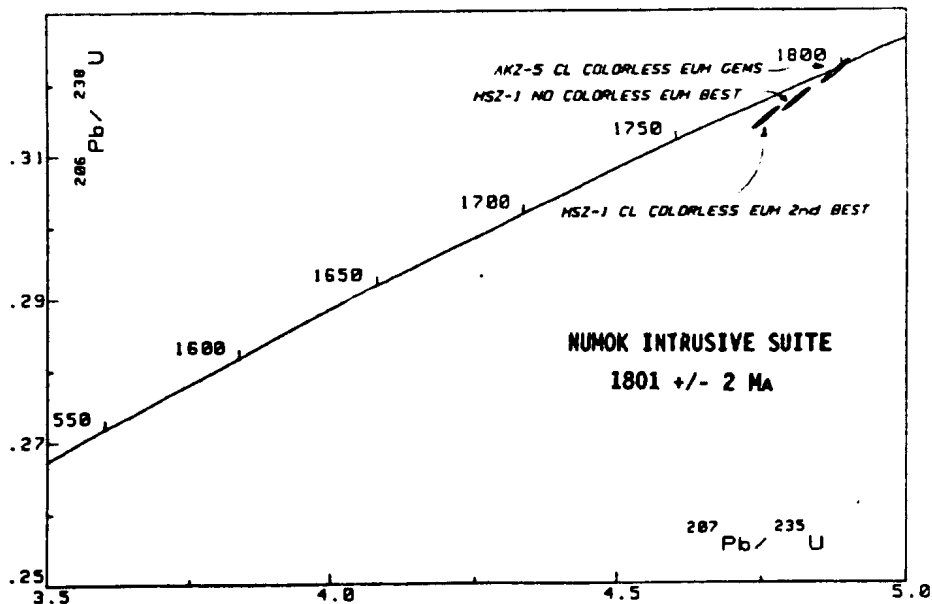
Figure D.3. $^{206}Pb/^{238}U$ - $^{207}Pb/^{235}U$ concordia diagram for
units of the Numok Intrusive Suite.
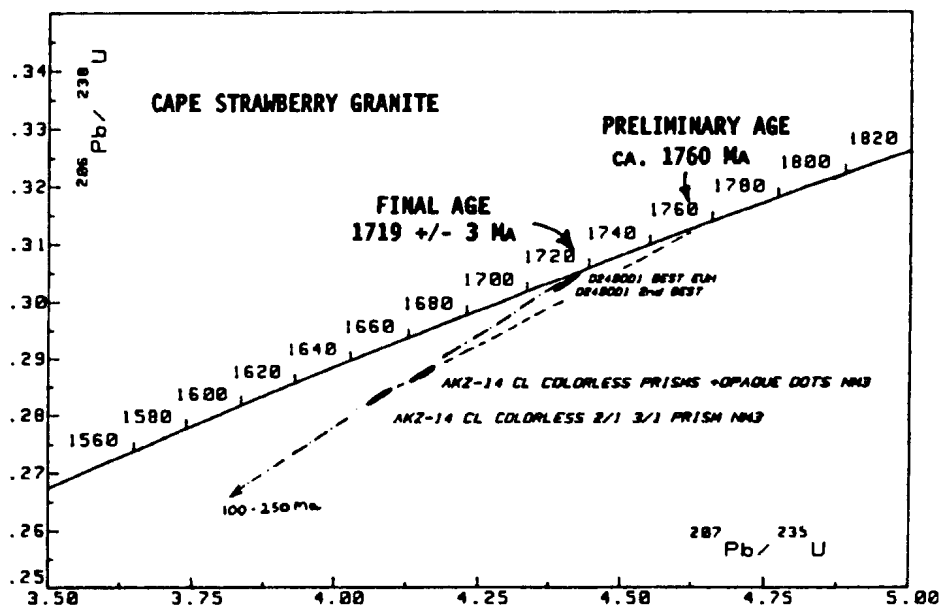
Figure D.4. $^{206}Pb/^{238}U$ - $^{207}Pb/^{235}U$ concordia diagram for
The Cape Strawberry Granite, incorporating preliminary data and
new data obtained in the spring of 1989.

Cape Strawberry Granite -- Preliminary Data

Sample AKZ-14 (located in Figure 8.4) is a coarse-grained fluorite-bearing granite. It yielded two discordant zircon fractions that are well removed from concordia and lie (generally) along a line from 1800 Ma (concordia) to ca. 1000 Ma (lower intercept). Interpretation of these data is difficult. Drawing a line through the two points indicates an age of ca. 1760 Ma, but this is not a rigorous regression procedure. Assuming a 1000 Ma lower intercept suggests an age close to 1800 Ma (Figure D.4). It is evident, however, that a Labradorian (ca. 1650 Ma) age is highly unlikely, unless the zircons have a very unusual history of Pb loss. The 1760 Ma estimate was preferred during preparation of this thesis, as it is consistent with field evidence suggesting that the related Dog Islands Granite is younger than the Numok Intrusive Suite (Chapter 4).

Cape Strawberry Granite -- Spring 1989 Update

T.Krogh (pers.comm., 1988), suggested that the evolved geochemistry of AKZ-14 was responsible for problems with Pb loss, and proposed that another (preferably more "mafic") sample should be examined. Sample 0249001 is from a biotite-rich "cumulate" band exposed several hundred metres south of AKZ-14, which is gradational with identical coarse-grained granite. A small sample contained abundant, euhedral, "cumulus" zircon prisms, witn no sign of inheritance. Two frac ions are less than 1% discordant, and indicate a precise age of 1719 ± 3 Ma (Figure D.4), some 40 Ma younger than the preliminary estimate of 1760 Ma. These data are not fully colinear with AKZ-14, but if regressed

with these preliminary data, give a lower intercept of 100
- 250 Ma. This revised 1719 Ma age significantly extends
the duration of post-tectonic Makkovikian plutonism in the
study area.

Mount Benedict Intrusive Suite

Sample 0242144 (located in Figure 8.4) is a syenite
from near Mount Benedict. It contained stubby, euhedral
zircon prisms. Two unabraded fractions are discordant, and
plot in essentially the same location. However, a
Makkovikian age is highly improbable, and the ^{207}Pb/
^{206}Pb age of ca. 1642 Ma suggests a Labradorian affinity.
A second sample of less potassic material (0242125), from a
locality some 2 km north-east of 0242144, provided a
similar euhedral zircon population. Two fractions are very
slightly discordant, and indicate an age of ca. 1650 Ma.
Combination of the data yields an age of 1650 ± 10 Ma
(conservative error estimate), with a possible maximum age
of 1668 Ma if a 1000 Ma lower intercept is assumed.

Otter Lake - Walker Lake Granitoid

Sample AKZ-8 (located in Figure 8.4) is a seriate to
porphyritic two-feldspar quartz monzonite to monzogranite.
It yielded cracked, euhedral zircons. Two abraded fractions
were concordant and 1.2% discordant respectively, and
indicate a precise age of 1647 ± 2 Ma (Figure D.6). This is
within error of the Bruce River Group (as determined by
Scharer et al., 1988), which was proposed by Ryan (1984) as
a volcanic equivalent of the Otter Lake - Walker Lake unit.
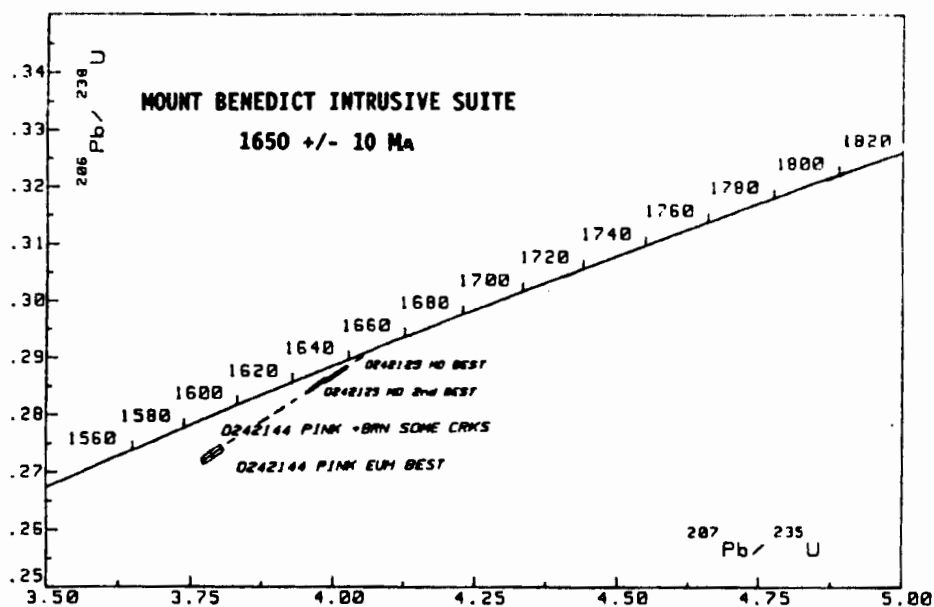
Figure D.5. $^{206}Pb/^{238}U$ – $^{207}Pb/^{235}U$ concordia diagram for
Syenite of the Mount Benedict Intrusive Suite.
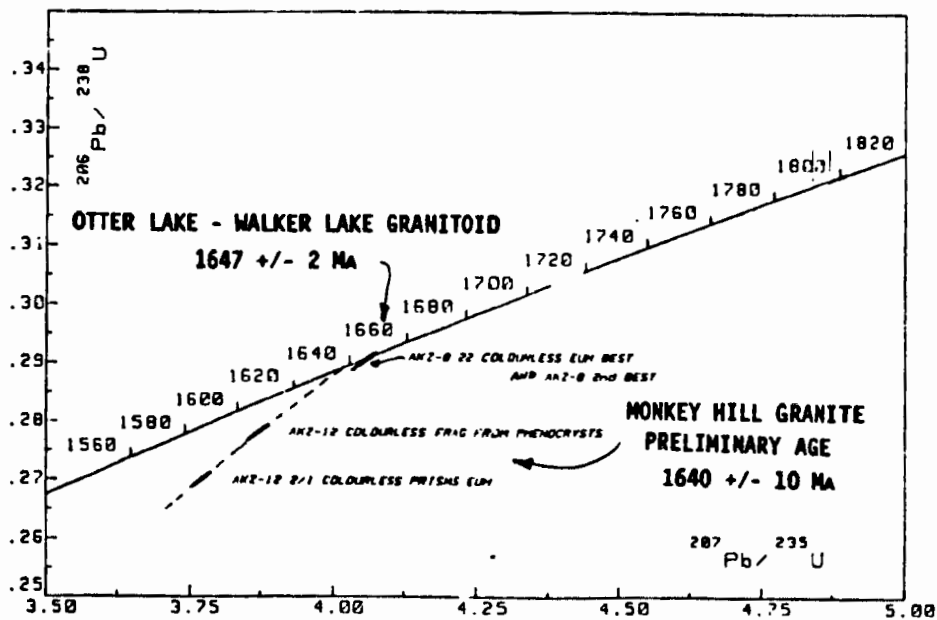
Figure D.6. $^{206}Pb/^{238}U$ – $^{207}Pb/^{235}U$ concordia diagram for
the Otter Lake – Walker Lake Granitoid and the Monkey Hill
Granite.

- 526 -
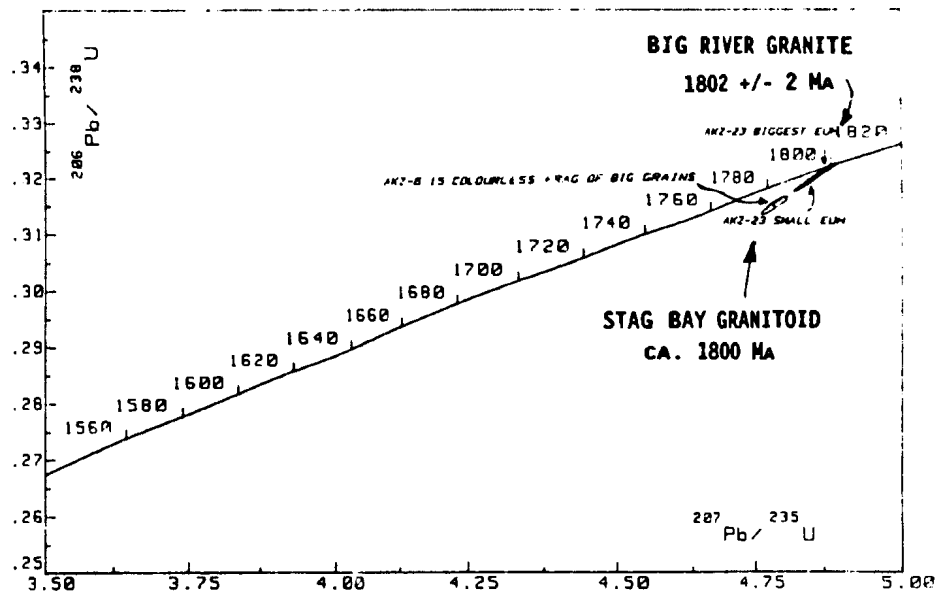
Figure D.7. $^{206}Pb/^{238}U$ - $^{207}Pb/^{235}U$ concordia diagram for
the Big River Granite and Stag Bay Granitoid, for which data were
obtained in the spring of 1989.

Monkey Hill Intrusive Suite

Sample AKZ-12 (located in Figure 8.4) is a medium-grained equigranular granite from the main Monkey Hill Granite pluton. It contained only a small amount of zircon, consistent with the generally Zr-poor nature of these rocks (Chapter 5). Two abraded fractions are 4% and 7% discordant (Figure D.6). Placing a line through the two points suggests an age of 1640 Ma or less, whereas a regression incorporating AKZ-8 indicates an age of 1648 +3 / -2 Ma. To cover all possibilities, a preliminary age of 1640 ± 10 Ma is suggested here. There is no doubt that the unit is of Labradorian age. This preliminary age brackets the 1632 ± 9 Ma age (Brooks, 1983) from the compositionally similar Witchdoctor Granite.

Big River Granite

Sample AKZ-23 is located several kilometres southeast of O241538 (located in Figure 8.4), and is a typical coarse-grained pseudorapakivi granite. Two fractions of crack-free grains are 0.4% and 1.1% discordant, and indicate a precise age of 1802 ± 2 Ma (Figure D.7), that agrees well with the 1798 ± 28 Ma Rb-Sr age (Chapter 8).

Stag Bay Granitoid

Sample AKZ-6 (located in Figure 8.4) is a K-feldspar porphyritic granite. Two fractions of broken zircon were separated, but one was lost during mass spectrometry. The remaining fraction is 2.6% discordant, but indicates a Makkovikian age of ca. 1800 Ma. This shows that the 1714 ± 44 Ma Rb-Sr isochron obtained during this project (Chapter 8) is erroneously young.

APPENDIX E : GEOLOGICAL AND TOPOGRAPHIC MAPS

Three enclosures are provided. Enclosure 1 is a
1:250,000 summary map of plutonic rocks in the study area,
with a companion legend (Enclosure 2). Note that this is
intended as a summary map to illustrate the distribution of
units, and the geology has been simplified to accomodate
the relatively small scale. Quaternary deposits are not
shown, and it should be noted that large areas south of the
Benedict Fault, around Big River, and north of MacLean Lake
are largely or completely obscured.

This map is a combination of mapping conducted during
this project, and previous work compiled from Gower (1981),
Gower et al. (1982) and Ryan (1984). All details of
supracrustal rocks have been compiled from these sources,
as have some external contacts of plutonic units.

The map and legend were prepared using the GSDRAW and
GSMAP cartography computer programs developed by the United
States Geological Survey, and modified by Larry Nolan of
the Newfoundland Department of Mines. Ken Byrne and the
staff of the Department of Mines Cartography and Drafting
Section prepared the final composite negatives.

A 1:250,000 scale topographic map is included to allow
reference to localities not labelled on Enclosure 1. This
is derived from NTS 1:250,000 sheets 13K (Snegamook Lake),
13J (Rigolet), 13O (Makkovik) and 13I (Groswater Bay).

ENCLOSURE I

0 ——— 160
KM

-N-

Bay of Islands

18

AREA OF MAP

Kaipokok Bay

13

LABRADOR
QUEBEC

INDEX MAP

18

0

A

23

61

kok Bay

Scale 1:250,000

5   0   5   10   15

Kilometres

Dunn Island

Ironbound Islands

1.1

45.6

1.2

Kidlaluit Island

Cape Strawberry

24.1

1.2

Pomiadluk Point

1.2

20.1

24.3

24.2

1.2

h

24.2

20.1

Big Bight

21.1

24.2

20.1

20.1

15

21.1

20.1

40.1

Adlavik Islands

21.1

Ragged Islands

1.2

Manak Island

20.1

15

Kikkertavak (Numok) Island

40.1

20.1

41.1

20.1

21.1

Web

1.1

20.1

20.1

Adlavik Bay

20.1

41.1

27

21.1

40.1

20.1

Iron Island

Dog Island

Double Island

Deus Cape

41.1

25

1.2

1.1

1.2

40.1

Lanceground Bay

40.4

25

Burnt Island

1.2

30.2

Big River

40.4

26   Bear Island

16

Pamiulik Point

30.1

1.1

40.4

21.1

30.1

62

26

30.2

1.4

26

Tukialik R

20

-N-

ds

ebeck Island   Cape Harrison

17

17

17

Jeanette Bay

16

INDEX MAP

West MicMac Lake

East MicMac Lake

Kaipokok Bay

MacLean Lake

Walker Lake

Witchdoctor Lake

18

0

07

0

23

2

61

61

1.2

72

23

40.3

12

1.1

12

41.3

1.1

12

48

48

48

48

48

48

46

47

46

47

46

46

1.2

1.2

1.2

66

0

10.2

10.2

1.2

2

A

A

A

A

Iron Island

Adlavik Bay

Lanceground Bay

Big River

11.4

11.3

23

60

1.2

28

27

20.1

20.1

25

40.1

41.1

40.1

40.4

21.2

1.21

29

1.3

22.2

20.2

40.2

41.2

20.2

30.1

30.1

30.1

30.2

30.2

30.1

62

62

64

66

66

29

29

66

66

66

Adlavik Bay

20.1 20.1 21.1

Iron Island 25

Dog Island

Double Island 1.1 1.2 1.2

Deus Cape 1.2

27

40.1 41.1 40.1 Lanceground Bay 40.4 25 Burnt Island

16

30.2 Big River 30.1 30.2 62 62 64

30.1 30.1

1.1 40.4 Pamiulik Point 26 Bear Island 21.1

26 1.4 42 43 44 43 126 42

26 44 43

Tukialik Bay

66 66

66 Lake Michael 1.4 66

Jeanette Bay

17

17

17

16

16

16

63

43

16

66

Plutonic Rocks of The Makkovik Province

Unclassified and

`L 63 ┘` JEANETTE BAY QUARTZ SYENITE : Grey to pink, medium to coarse-grained, K-feldspar porphyritic, biotite-hornblende quartz syenite.

`▷62 ▽` STAG BAY GRANITOID : Grey to buff, coarse-grained, seriate to porphyritic biotite-hornblende granodiorite to granite. Phenocrysts of both feldspars.

1798 +/- 48 `60,61` FRESHSTEAK AND NOARSE LAKE GRANITOIDS : Grey to brown, medium-grained, variab plagioclase-porphyritic biotite-hornblende quartz monzonite to monzogranite.

Labradorian F

1(

MONKEY HILL INTRUSIVE SUITE

1640 +/- 10 `45` Grey to pink, fine to medium-grained, leucocratic, biotite-chlorite monzo-granite and granite, commonly slightly plagioclase-porphyritic.
45.1 - Monkey Hill Granite. 45.2 - Round Pond Granite. 45.3 - Duck Is. Granite. 45.4 - Little Monkey Hill Granite. 45.5 - Bent's Cove Granite 45.6 - Kidlaluit Granite. 45.7 - Other Units.

16

MOUNT BENEDICT INTRUSIVE SUITE

`44` Pink to buff, fine to medium-grained, equigranular to K-feldspar (+/- relict plagioclase porphyritic, biotite syenite to alkali-feldspar granite.

16

1650 +/- 10 `43` Grey to buff or pink, medium to coarse-grained, biotite - hornblende (+/-pyroxene monzonite, quartz monzonite and syenite. Relict (mantled) plagioclase phenocrysts impart a distinctive "speckled eggshell" texture.

`42` Grey to black-and-white, plagioclase-porphyritic, leucogabbro and diorite of probable cumulate origin. Resembles parts of Adlavik Intrusive Suite.

Post-Tectonic (generally mass

LANCEGROUND INTRUSIVE SUITE

`29` TARUN GRANITE : Variably foliated, buff to pink, medium to coarse-grained, biotite-hornblende quartz syenite, granite and alkali-feldspar granite.

1

`28` PISTOL LAKE GRANITE : Pink to buff, medium to coarse-grained, biotite-hornblende quartz syenite to alkali-feldspar granite, locally hypersolvus in texture.

`27` LANCEGROUND HILLS GRANITE : Pink to buff, medium to coarse-grained, biotite-hornblende quartz syenite to alkali-feldspar granite, locally hypersolvus.

NUMOK INTRUSIVE SUITE
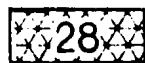
`22` Grey to dark brown, coarse grained, plagioclase-porphyritic pyroxene-hornblende monzodiorite and monzonite. Present only in the southern zone.

`21` Pink to brown, coarse grained, K-feldspar porphyritic, pyroxene-syenite and
1801 +/- 2 quartz syenite, locally with fayalitic olivine. Locally hypersolvus.

LEGEND

id Other Plutonic Rocks

ıar   1426 **88** MICHAEL GABBRO SUITE :
Grey to black, medium to coarse-grained, olivine gabbro and diabase, with
minor leucogabbro and diorite.

..66.. GRANITOID GNEISSES OF THE GRENVILLE STRUCTURAL PROVINCE
Foliated granitoid rocks and granitoid gneisses, variably K-feldspar
porphyritic and/or augen textured. Locally cataclastic or mylonitic.

ably ◇64◇ THUNDER MOUNTAIN SYENITE : Pink to brown, coarse-grained, K-feldspar porphyritic
hornblende (+/- pyroxene) syenite and quartz syenite, with blue quartz.
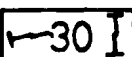
Plutonic Rocks

164? +/- 2 48 OTTER LAKE - WALKER LAKE GRANITOID : Grey to pink, medium to coarse-grained,
seriate to porphyritic, biotite-hornblende quartz monzonite to monzogranite.
Generally fresh, massive and little-deformed; locally foliated.

47 BURNT LAKE GRANITE : Grey, white or pink, fine to medium-grained, leucocratic
biotite (+/- muscovite) monzogranite and granite. Locally contains minor garnet.

1632 +/- 9 46 WITCHDOCTOR GRANITE : White to pink, medium to coarse-grained, leucocratic,
biotite-muscovite granite, containing accessory garnet. Variably foliated.
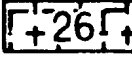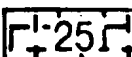
ADLAVIK INTRUSIVE SUITE

1649 +/- 1 41 Grey to yellow-brown, coarse-grained, pyroxene-hornblende diorite and
monzodiorite. Locally displays cumulate texture or layering. Subdivisions as
as for Unit 40 (below). Locally syenitic in appearance.

40 Grey to green or brown, coarse-grained gabbro, gabbronorite and leucogabbro.
Includes ultramafic and mafic cumulates, massive and composite diabase, and
hornblende-plagioclase 'pegmatite'. 40.1 - Main Body (Adlavik Bay). 40.2 - Big
40.3 - East McMac Lake. 40.4 - Eastern bodies, including Pamiulik Point.

sive) Makkovikian Plutonic Rocks

1798 +/- 28 30 BIG RIVER GRANITE : 30.1 - pink to red, coarse grained, K-feldspar porphyritic,
biotite-hornblende granite with pseudorapakivi texture. 30.2 - equigranular
to locally quartz-porphyritic phase of generally similar composition.

STRAWBERRY INTRUSIVE SUITE

26 TUKIALIK GRANITE : Pink to red, coarse-grained, K-feldspar porphyritic, biotite
granite and alkali-feldspar granite, containing accessory fluorite.

25 DOG ISLANDS GRANITE : Pink, coarse-grained, K-feldspar (+/- quartz) porphyritic
biotite-granite, alkali-feldspar granite and quartz-feldspar porphyry, commonly
with abundant accessory fluorite.

CAPE STRAWBERRY GRANITE AND ASSOCIATED ROCKS
1760 +/- 10 ? 24 White, pink or red, generally coarse grained, texturally varied, K-feldspar

0   160

-N-

MAP AREA

Island   Hares   ISLANDS

Striped

ISLAN

OF   ISLAN

The
Sisters

English
River I

Po Postville

POST
HILL

Rapids

R

Salmon Pond R.

Makkovik
Back

IPOKOK

LANDS

~ Striped

(pos approx)

Turnavik
Island
TURNAVIK
ISLANDS
West Turnavik

C Makkovik

Ailik

Dunn I

Black
Islands

Strawberry
Island

Ironbound
Islands

Drunken
Hd   402

C Roy

901

Belle I

Cape
Strawberry

1225

Pomiadluk
Pt

Wild
Bight

Foxy
Is

KAIPOKOK   BAY

Long Island

BAY

370

MAKKOVIK   Big I

Makkovik
Hr

Rapids

Double

Izziuk
Bight

ADLAVIK

Long
Tickle
Island

Manak

Marko
Bight

Big Bight

ADLAVIK

The
Sisters

MONKEY
HILL

Manak

ISLAND

Makkovik
Bay

Rapids

ADLAVIK

ISLAND

Makkovik   River

Adlavik Bay

Indian

Porcupine

Adlavik   Brook

Hog

Dunn I

Strawberry
Island

Ironbound
Islands

Kidlialuit Island

Belle I

Cape
Strawberry

Pomiadiuk
Pt

Wild
Bight

Foxy
Is

Double I

Black Bear
Island

Long
Tickle
Island

ADLAVIK

ISLANDS

Kikkertavak
Island

Ragged
Islands

Ragged
Islands

Kikkertavak Island

Tikaoralu
Islet

ADLAVIK

ISLANDS

Conical

L A B R A D O R   S E A

Deus
Cape

Jigger

Dog
Islands

Iron
Island

Double
Island

Porcupine

Dog I

Island

Burnt

Bear

Stag
Bay

:250,000

-N-

Morrison

Webeck

Cape Harrison

UIVALUK
PK

Bear

Sloop
Cove

False Cape

Loud Arm

LANCEGROUND INTRUSIVE SUITE

29 TARUN GRANITE : Variably foliated, buff to pink, medium to coarse-grained, biotite-hornblende quartz syenite, granite and alkali-feldspar granite.

28 PISTOL LAKE GRANITE : Pink to buff, medium to coarse-grained, biotite-hornblende quartz syenite to alkali-feldspar granite, locally hypersolvus in texture.

27 LANCEGROUND HILLS GRANITE : Pink to buff, medium to coarse-grained, biotite-hornblende quartz syenite to alkali-feldspar granite, locally hypersolvus.

NUMOK INTRUSIVE SUITE

22 Grey to dark brown, coarse grained, plagioclase-porphyritic pyroxene-hornblende monzodiorite and monzonite. Present only in the southern zone.

1801 +/- 2   **21** Pink to brown, coarse grained, K-feldspar porphyritic, pyroxene-syenite and quartz syenite, locally with fayalitic olivine. Locally hypersolvus.   17(
21.1 - Northern Zone (Adlavik Islands) 21.2 Southern Zone (Big River).   17
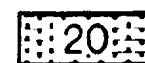
1801 +/- 2   **20** White to pink, medium to coarse-grained, variably plagioclase and K-feldspar porphyritic, hornblende-biotite monzonite, quartz monzonite and syenite.
20.1 - Northern Zone (Adlavik Islands). 20.2 - Southern Zone (Big River).

Syn-Tectonic (generally foliated) Makkovikian Plutonic Rocks

1805 +/- 5   **18** ISLAND HARBOUR BAY INTRUSIVE SUITE : Compositionally and texturally variable diorite, tonalite, quartz monzonite, granodiorite and granite.

1837 +6/-4   **16** DEUS CAPE GRANITOID : Pink to grey, coarse grained, seriate to K-feldspar megacrystic, foliated biotite-hornblende granodiorite to granite.

14 PITRE LAKE GRANITE : White to pale pink, medium-grained, equigranular biotite-muscovite leucogranite with "ghost layering" and metasedimentary xenoliths.

12 MELODY GRANITE : Pink to brick-red, coarse grained, variably K-feldspar porphyritic, strongly foliated, biotite granite, generally leucocratic.

1802 +13/-7   **10** LONG ISLAND QUARTZ MONZONITE : Grey-brown, fine to medium grained, melanocrati(plagioclase-porphyritic biotite-hornblendequartz monzonite to monzogranite
10.1 - Main Body (Long Is - Mark's Bight) 10.2 - Other units.

MAKKOVIKIAN OR PRE-MAKKOV

1861 +9/-3   **1** EARLY UPPER AILLIK GROUP : Arkose, bedded tuff, sandstone, siltstone,   1(conglomerate, agglomerated, and minor mafic to felsic metavolcanic rocks.   1

0 LOWER AILLIK GROUP : Amphibolites, pelitic to psammitic metasedimentary rocks, mafic metavolcanic rocks and silicate-oxide iron formation.
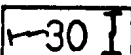
ARCHEAN OR PRE-MAKKOVI

> 2800   **A** ARCHEAN BASEMENT ROCKS (Western Domain Only) : Strongly layered and foliated orthogneisses of tonalite-granodiorite composition, intercalated with   2100 amphibolites, and cut by massive to foliated granitoid rocks.
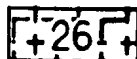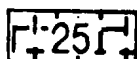
ssive) Makkovikian Plutonic Rocks

1798 +/- 28 `[─30 I]` **BIG RIVER GRANITE** : 30.1 – pink to red, coarse grained, K–feldspar porphyritic, biotite–hornblende granite with pseudorapakivi texture. 30.2 – equigranular to locally quartz–porphyritic phase of generally similar composition.

STRAWBERRY INTRUSIVE SUITE

`[+26]` **TUKIALIK GRANITE** : Pink to red, coarse–grained, K–feldspar porphyritic, biotite granite and alkali–feldspar granite, containing accessory fluorite.

`[+25]` **DOG ISLANDS GRANITE** : Pink, coarse–grained, K–feldspar (+/– quartz) porphyritic biotite–granite, alkali–feldspar granite and quartz–feldspar porphyry, commonly with abundant accessory fluorite.

1760 +/- 10 ? `[+24]` **CAPE STRAWBERRY GRANITE AND ASSOCIATED ROCKS**
1719 +/- 3 White, pink or red, generally coarse grained, texturally varied, K–feldspar porphyritic, biotite granite to alkali–feldspar granite with fluorite. 24.1 – Cape Strawberry Granite. 24.2 – October Harbour Granite. 24.3 – Poodle Pond Granite Sills. 24.4 – Other Minor intrusions.

`[+23]` **BAYHEAD GRANITE** : White to pink, medium–coarse grained, K–feldspar porphyritic biotite granite, monzogranite and alkali–feldspar granite with fluorite.
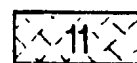
NOTE : SYN–TECTONIC MAKKOVIKIAN PLUTONIC ROCKS ARE CONSIDERED
TO BE 1800 Ma OR OLDER, BUT PROBABLY OVERLAP IN TIME WITH POST–
TECTONIC MAKKOVIKIAN PLUTONIC ROCKS.

`[15]` **MANAK ISLAND GRANITOID** : White to pale grey, medium to coarse–grained, leucocratic, foliated biotite–hornblende granodiorite to monzogranite.

`[13]` **BRUMWATER GRANITE** : Grey to pink, medium–grained, equigranular, foliated, biotite–granite and monzogranite, with gneissic xenoliths.

`[11]` **KENNEDY MOUNTAIN INTRUSIVE SUITE**
Dominantly pink to white or buff, medium–coarse grained, leucocratic, variably K–feldspar porphyritic, foliated biotite monzogranite and granite containg accessory fluorite. Locally alaskitic. 11.1 – Kennedy Mountain Granite
ratic 11.2 – Narrows Granite. 11.3 – Cross Lake Granite. 11.4 – Other units.
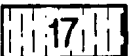
OVIKIAN SUPRACRUSTAL ROCKS

1856 +/- 2 `[1]` **LATE UPPER AILLIK GROUP AND POSSIBLE CORRELATIVES**
1807 +/- 3 1.0 – Undifferentiated . 1.2 – Felsic tuffs and pyroclastic rocks, massive rhyolites and minor tuffaceous metasedimentary rocks. 1.3 – Massive subvolcanic quartz–porphyry and quartz–feldspar porphyry. 1.4 – Jagged Edge Assemblage volcanic rocks. 1.5 – Jagged Edge Assemblage subvolcanic intrusive rocks. NOTE : Jagged Edge Assemblage may be younger than Upper Aillik Group.
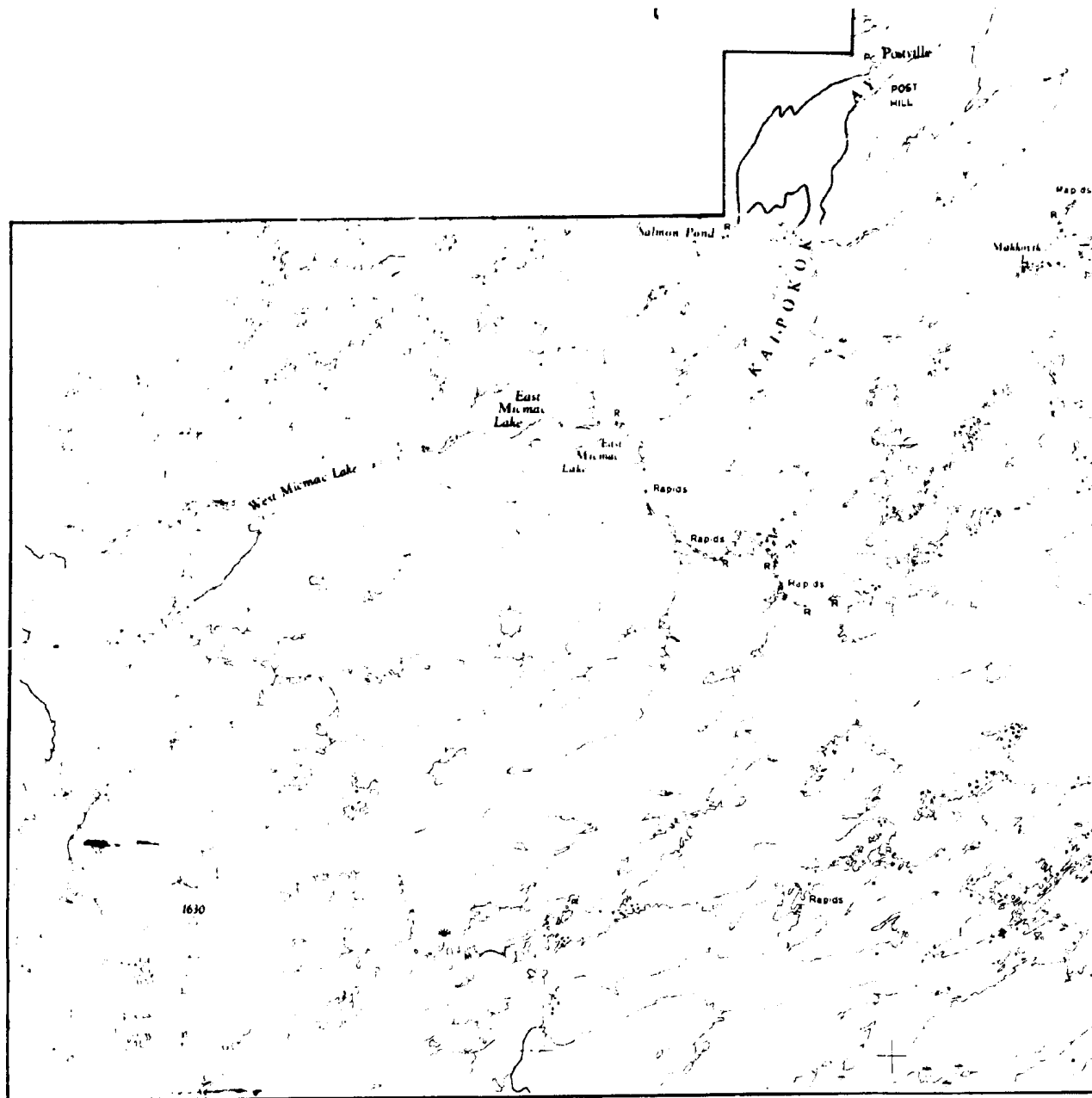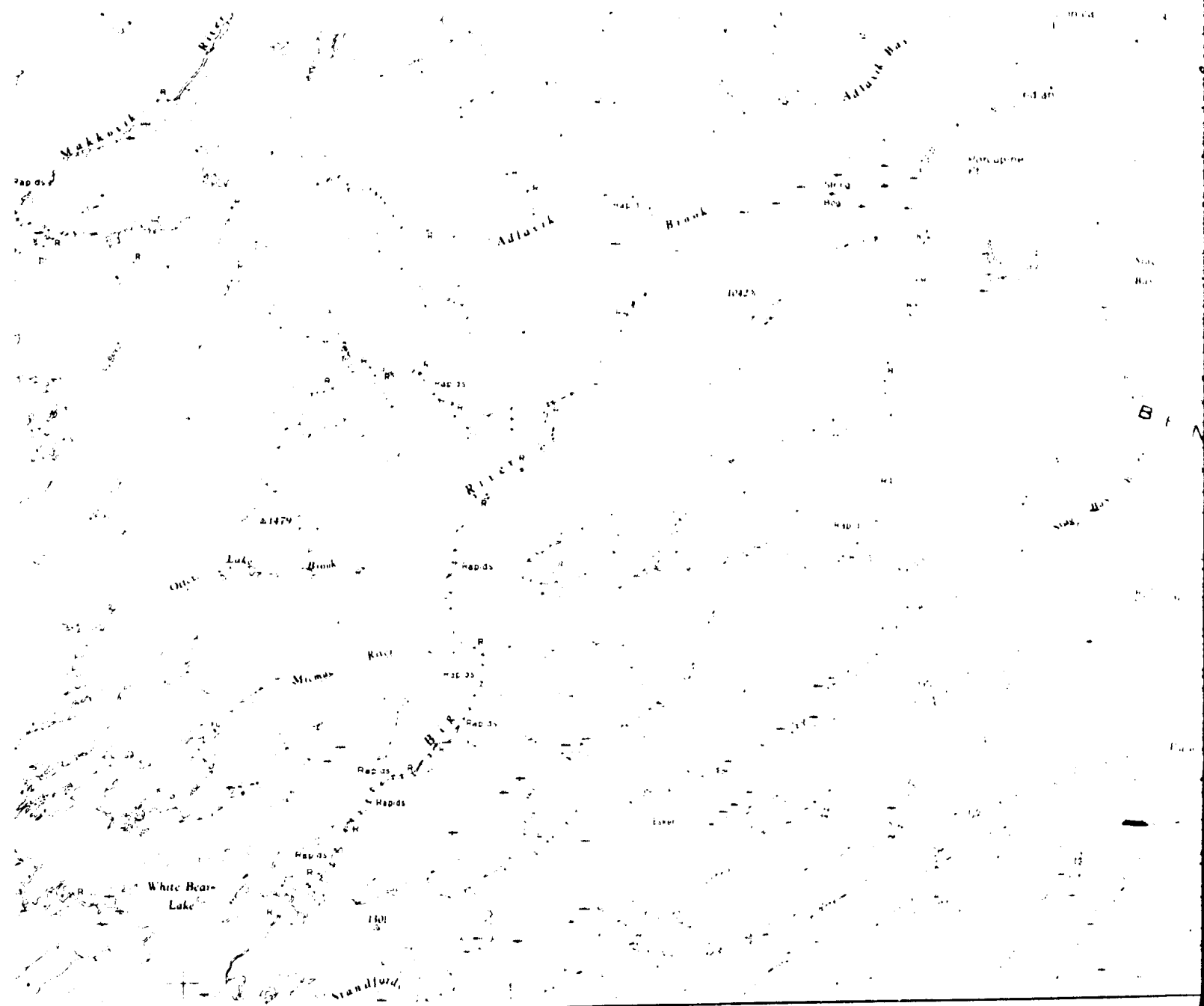
VIKIAN (?) BASEMENT ROCKS

100 – 1900 ? `[17]` **CAPE HARRISON METAMORPHIC SUITE** : Strongly layered, banded and foliated orthogneisses of diorite to granodiorite composition, associated with foliated granitoid rocks, and remnants of supracrustal material.
Similar to Archean rocks in field appearance, but probably Proterozoic.

Pottyllr

POST
HILL

Salmon Pond

KAIPOKOK

Rap ds

Mukkuvik

East
Micmac
Lake

West Micmac Lake

East
Micmac
Lake

Rapids

Rapids

Rapids

Rapids

1630

Makkovik

Adlavik Bay

Porcupine

Adlavik Brook

Rapids

River

Chu... Lake   Brook

Rapids

River

Minmix   River

Rapids

Rapids

Rapids

White Bear-
Lake

Rapids

Strandfjord

L A B R A D O R   S E A

Deus
Cape

Dog
Islands

Double

Island

Burnt

Bear

Pamialik
Bas

Tukialik
Bas

B E N E D I C T

MOUNT
BENEDICT

M O U N T A I N S

Rapids   Rapids

Rapids

Rapids

Pamialik

Lake

Michael

Morrison
Webeck
UIVALUK Pk
Bear
Sloop Cove
False Cape
Lord Arm
Seal Rocks
Jeanette Bay
Jeanette Bay
Ship Hd
Moran Cove
Moran Cow
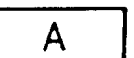Ruby Brook
Rapids
Rapids
Rapids
Rapids

Syn-Tectonic (generally foliated) Makkovikian Plutonic Rocks

1805 +/- 5   **18**   ISLAND HARBOUR BAY INTRUSIVE SUITE : Compositionally and texturally variable diorite, tonalite, quartz monzonite, granodiorite and granite.

1837 +6/-4   **16**   DEUS CAPE GRANITOID : Pink to grey, coarse grained, seriate to K-feldspar megacrystic, foliated biotite–hornblende granodiorite to granite.

   14   PITRE LAKE GRANITE : White to pale pink, medium-grained, equigranular biotite–muscovite leucogranite with "ghost layering" and metasedimentary xenoliths.

   12   MELODY GRANITE : Pink to brick–red, coarse grained, variably K-feldspar porphyritic, strongly foliated, biotite granite, generally leucocratic.

1802 +13/-7   **10**   LONG ISLAND QUARTZ MONZONITE : Grey–brown, fine to medium grained, melanocrat plagioclase-porphyritic biotite–hornblendequartz monzonite to monzogranite
10.1 – Main Body (Long Is – Mark's Bight) 10.2 – Other units.

MAKKOVIKIAN OR PRE-MAKKO'

1861 +9/-3   **1**   EARLY UPPER AILLIK GROUP : Arkose, bedded tuff, sandstone, siltstone, conglomerate, agglomerated, and minor mafic to felsic metavolcanic rocks.

   0   LOWER AILLIK GROUP : Amphibolites, pelitic to psammitic metasedimentary rocks, mafic metavolcanic rocks and silicate–oxide iron formation.

ARCHEAN OR PRE-MAKKOV

> 2800   **A**   ARCHEAN BASEMENT ROCKS (Western Domain Only) : Strongly layered and foliated orthogneisses of tonalite–granodiorite composition, intercalated with amphibolites, and cut by massive to foliated granitoid rocks.   210

GEOLOGICAL SYMBOLS

– – – – Geological contact (defined, approximate)

. . . . Geological contact (inferred, position uncertain)

~~~~~ Fault (defined, approximate)

~~~~~ Fault (inferred, position uncertain)

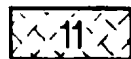⟨⟩ Foliation and/or layering (tick indicates dip direction)

15 MANAK ISLAND GRANITOID : White to pale grey, medium to coarse-grained, leucocratic, foliated biotite-hornblende granodiorite to monzogranite.

13 BRUMWATER GRANITE : Grey to pink, medium-grained, equigranular, foliated, biotite-granite and monzogranite, with gneissic xenoliths.

11 KENNEDY MOUNTAIN INTRUSIVE SUITE
Dominantly pink to white or buff, medium-coarse grained, leucocratic, variably K-feldspar porphyritic, foliated biotite monzogranite and granite containg accessory fluorite. Locally alaskitic. 11.1 – Kennedy Mountain Granite 11.2 – Narrows Granite. 11.3 – Cross Lake Granite. 11.4 – Other units.

:ratic

OVIKIAN SUPRACRUSTAL ROCKS

LATE UPPER AILLIK GROUP AND POSSIBLE CORRELATIVES

1856 +/- 2
1807 +/- 3 **1** 1.0 – Undifferentiated . 1.2 – Felsic tuffs and pyroclastic rocks, massive rhyolites and minor tuffaceous metasedimentary rocks. 1.3 – Massive subvolcanic quartz-porphyry and quartz-feldspar porphyry. 1.4 – Jagged Edge Assemblage volcanic rocks. 1.5 – Jagged Edge Assemblage subvolcanic intrusive rocks. NOTE : Jagged Edge Assemblage may be younger than Upper Aillik Group.

)VIKIAN (?) BASEMENT ROCKS

2100 – 1900 ? **17** CAPE HARRISON METAMORPHIC SUITE : Strongly layered, banded and foliated orthogneisses of diorite to granodiorite composition, associated with foliated granitoid rocks, and remnants of supracrustal material. Similar to Archean rocks in field appearance, but probably Proterozoic.

NOTES AND REFERENCES

This 1:250,000 scale map is intended as a summary only. It represents a combination of previous mapping by Department of Mines personnel, and also mapping carried out under this project. Differences between this and previous maps listed below lie in the distribution and grouping of intrusive rocks, particularily in inland areas. The distribution and grouping of other rock types is largely unaltered, although some simplification has been attempted. Sources used in compilation are as follows :

Gower,C.F. 1981 . Geology of the Benedict Mountains, Labrador . MDD Report 81-3.

Gower, C.F., Flanagan,M.J., Kerr, A. and Bailey,D.G. 1982 . Geology of the Kaipokok Bay-Big River Area, Labrador. MDD Report 82-7.

Ryan, A.B. 1985. Regional geology of the central part of the Central Mineral Belt, Labrador. M.D.D. Memoir 3.

EARLY PROTEROZOIC GRANITOID MAGMATISM AND CRUSTAL EVOLUTION IN THE MAKKOVIK PROVINCE OF LABRADOR: A GEOCHEMICAL AND ISOTOPIC STUDY

ANDREW KERR, B. Sc., M. Sc.