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UMI
Petrography and Structural Petrology of the Aldermae Syenite Igneous Complex and its Related Dikes

by

Christopher Fratton

A thesis submitted in conformity with the requirements for the degree of Master of Science
Graduate Department of Geology
University of Toronto

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PETROGRAPHY AND STRUCTURAL PETROLOGY OF THE ALDERMAC SYENITE IGNEOUS COMPLEX AND ITS RELATED DIKES

M.Sc. thesis, 1998, Christopher Fratton,
Department of Geology, University of Toronto

ABSTRACT

An alkaline igneous pluton, locally known as the Syenite Igneous Complex (SIC), and a petrologically similar dike swarm, are intruded into host volcanic rocks of the Blake River Group, near Aldermac, Quebec. The lithologically heterogeneous SIC consists of variously striking vertical sheets, and the related dikes are also vertical and generally radiating around the SIC. Both dikes and SIC are thought to be in their original emplacement orientation. All are characterised by primary igneous megacrysts that often exhibit a strong shape-preferred orientation (SPO). Petrographic and textural analyses indicate fractionation of magma at all scales, including late stage extrusion of residual melt (filter pressing). SPOs preserved in dikes and tabular bodies within the SIC, record a progressive history of freezing of magma in tabular intrusive bodies, inhibition of megacryst rotation by flow margins and grain interactions, late stage filter pressing of the magma, and ultimate channelling along discrete tubes.
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# Table of Contents

**Abstract** ........................................................................................................ II

**Acknowledgements** ...................................................................................... III

**Table of Contents** ........................................................................................ IV

**List of Tables** ................................................................................................ VII

**List of Plates** ................................................................................................ VIII

**List of Figures** ................................................................................................ IX

**List of Maps** ................................................................................................ X

**Chapter I: General Introduction** ................................................................. 1-1

- Introduction ........................................................................................................ 1-1
- Theoretical Background .................................................................................... 1-1
- Aldermac Study Area ....................................................................................... 1-3
  - Brief History .................................................................................................. 1-3
  - General Geology ............................................................................................ 1-3
- Analytical Methods .......................................................................................... 1-4
- Outline of Thesis Chapters and Rationale for Ordering .................................. 1-4
  - Chapter I ........................................................................................................ 1-4
  - Chapter II ....................................................................................................... 1-5
  - Chapter III ...................................................................................................... 1-5
  - Chapter IV ...................................................................................................... 1-5
  - Chapter V ........................................................................................................ 1-6

**Chapter II: Geological Setting** ................................................................... 2-1

- Introduction ........................................................................................................ 2-1
- Regional Geology .............................................................................................. 2-1
  - Superior Province ........................................................................................... 2-1
  - Abitibi Subprovince ......................................................................................... 2-2
  - The Southern Abitibi Greenstone Belt (SAGB) and the Rouyn Noranda Mining Belt .................. 2-3
  - Topography and Access ................................................................................ 2-4
- General Geology of the Aldermac Property ................................................... 2-5
  - Volcanics ......................................................................................................... 2-5
  - Syenite Intrusive Complex (SIC) ................................................................. 2-6
  - Syenite/Trachyte Dikes .................................................................................. 2-6
  - Other Petrologic Features .............................................................................. 2-7
  - Emplacement History and Igneous Environment ...................................... 2-8

**Chapter III: Petrographic and Petrologic Analysis of the Aldermac Mine Area** 3-1

- Abstract ............................................................................................................ 3-1
- Introduction ....................................................................................................... 3-1
  - Textures and Fabrics in Igneous Rocks ....................................................... 3-2
- Methodology .................................................................................................... 3-3
- Volcanic Rocks ............................................................................................... 3-5
  - Felsic Volcanics ............................................................................................. 3-5
  - Mafic Volcanics ............................................................................................... 3-6
  - Related Intrusions .......................................................................................... 3-6
SYENITE IGNEOUS COMPLEX

Facies Variation and Timing Relationships
General Map Pattern of the SIC and Contact Relationships
SIC Facies
Biotite Pyroxene Syenite (BPS)
Biotite Amphibole Syenite (BAS)
Pyroxene Amphibole Syenite (PAS)
Green Amphibole Syenite (GAS)
Quartz Phryic Syenite (QPS)
Amphibole-Quartz Syenite (AQS)
SYENITE/TRACHYTE PORPHYRY DIKES
Facies Classification Scheme
Facies Variation and Timing Relationships
General Map Pattern of Dikes
Dike facies
Biotite Pyroxene Dikes (BPD)
Biotite Amphibole Dikes (BAD)
Amphibole Quartz Dikes (AQD)
Quartz Feldspar Porphyry Dikes (QFD)
Quartz Amphibole Dikes (QAD)
Dike Orientations
Other Petrologic and Structural Features of the Area
Veins
Faults and Joints
DISCUSSION
Megacryst Crystallisation History
Modal Variability and Source Magma Chamber Fractionation
Feldspar Modes and In situ Fractionation
SUMMARY

CHAPTER IV: SHAPE PREFERRED ORIENTATIONS OF MINERAL GRAINS IN THE ALDERMAC SYENITE IGNEOUS COMPLEX AND DIKES

ABSTRACT
INTRODUCTION
Flow and Flow Direction Indicators in Dikes, A Review
Fabrics and Textures as magma flow indicators
Igneous Shape-Preferred Orientations
The Jeffery Model
Timing of fabric acquisition
The Aldermac Syenite Igneous Complex and related Dikes
ANALYTICAL METHODS
SYENITE INTRUSIVE COMPLEX
Fabrics in the SIC
SPO-Defined Foliations
SPO-Defined Lineations
Other SPOs
Fabrics and Contacts
SYENITE/TRACHYTE PORPHYRY DIKES
Fabrics in Dikes
SPO-Defined Lineations
SPO-Defined Foliations and Related Fabrics
DISCUSSION
SPO Fabrics in the Aldermac Intrusive Rocks
Simple Shear Flow Models of SPO Fabric Acquisition
Proposed Model of SPO Acquisition: Freezing-Wall Accretion
Application of the Freezing-Wall Accretion Model at Aldermac
Alternative Models of SPO Fabric Acquisition at Aldermac
Proposed Model of SPO Acquisition in the SIC: Filter Pressing
Proposed Model of SPO Acquisition in the Aldermac Dikes: Filter Pressing
LIST OF TABLES

Table 3.1. Minerals found in syenites. Some of the more distinctive and/or diagnostic.... 3-44
Table 3.2. Names of the six major facies found within the SIC; with equivalent.... 3-46
Table 3.3. Modal mineral compositions (volume percentage) for facies found within the SIC. 3-47
Table 3.4. Table of feldspar megacryst characteristics for all Facies Groups. 3-49
Table 3.5. Names of the five major dike facies found within and/or outside the SIC.... 3-49
Table 3.6. Modal mineral compositions (volume percentage) for dike facies. 3-50
Table 4.1. Classification of fabric intensity for SPO foliations in the Aldermac Mine area. 4-22
Table A1.1. Table of Dike orientation data in the Aldermac Mine area. A1-1
Table A1.2. Table of orientation data for veins in the Aldermac Mine area. A1-3
Table A1.3. Table of orientation data for other structural features of Aldermac Mine area. A1-4
Table A1.4. Table of foliation orientation data for the SIC. A1-5
Table A3.1. Classification of fabric intensity for SPO foliations in the Aldermac Mine area A3-4
Table A3.2. Table of results for the calibration of estimated strike and dip readings.... A3-4
Table A3.3. Table of foliation calibration test data. A3-5
### List of Plates

<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.</td>
<td>Syenite Intrusive Complex: contacts.</td>
<td>3-51</td>
</tr>
<tr>
<td>3.2.</td>
<td>Biotite Pyroxene Syenites (BPS): mineralogy and textures.</td>
<td>3-52</td>
</tr>
<tr>
<td>3.3.</td>
<td>Biotite Pyroxene Syenites (BPS): matrix mineralogy and textures.</td>
<td>3-53</td>
</tr>
<tr>
<td>3.4.</td>
<td>Biotite Pyroxene Syenites (BPS): textures.</td>
<td>3-54</td>
</tr>
<tr>
<td>3.5.</td>
<td>Biotite Pyroxene Syenites (BPS): varieties and fabrics.</td>
<td>3-55</td>
</tr>
<tr>
<td>3.6.</td>
<td>Biotite Amphibole Syenite (BAS) and Pyroxene Amphibole Syenite (PAS).</td>
<td>3-56</td>
</tr>
<tr>
<td>3.7.</td>
<td>Green Amphibole Syenite (GAS): mineralogy and textures.</td>
<td>3-57</td>
</tr>
<tr>
<td>3.8.</td>
<td>Green Amphibole Syenite (GAS): textures and fabrics.</td>
<td>3-58</td>
</tr>
<tr>
<td>3.9.</td>
<td>Quartz Phyric Syenite (QPS).</td>
<td>3-59</td>
</tr>
<tr>
<td>3.10.</td>
<td>Amphibole Quartz Syenite (AQS): mineralogy, textures, and fabrics.</td>
<td>3-60</td>
</tr>
<tr>
<td>3.11.</td>
<td>Biotite Pyroxene Dikes (BPD) and Quartz Feldspar Porphyry Dikes (QFD).</td>
<td>3-61</td>
</tr>
<tr>
<td>3.12.</td>
<td>Quartz Amphibole Dikes (QAD): mineralogy, textures, and fabrics.</td>
<td>3-62</td>
</tr>
<tr>
<td>3.13.</td>
<td>Cross-cutting relationships.</td>
<td>3-63</td>
</tr>
<tr>
<td>4.1.</td>
<td>Syenite Intrusive Complex: foliations.</td>
<td>4-27</td>
</tr>
<tr>
<td>4.2.</td>
<td>Syenite Intrusive Complex: foliations and lineations.</td>
<td>4-28</td>
</tr>
<tr>
<td>4.3.</td>
<td>Syenite Intrusive Complex: foliations and lineations continued.</td>
<td>4-29</td>
</tr>
<tr>
<td>4.4.</td>
<td>Syenite Intrusive Complex: variations of fabrics.</td>
<td>4-30</td>
</tr>
<tr>
<td>4.5.</td>
<td>Syenite Intrusive Complex: variations of fabrics, continued.</td>
<td>4-31</td>
</tr>
<tr>
<td>4.6.</td>
<td>Syenite/Trachyte Porphyry Dikes: fabrics.</td>
<td>4-32</td>
</tr>
<tr>
<td>4.7.</td>
<td>Syenite/Trachyte Porphyry Dikes: variations in fabrics.</td>
<td>4-33</td>
</tr>
<tr>
<td>4.8.</td>
<td>Syenite/Trachyte Porphyry Dikes: circles.</td>
<td>4-34</td>
</tr>
<tr>
<td>4.9.</td>
<td>Syenite/Trachyte Porphyry Dikes.</td>
<td>4-35</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 2.1. The central Superior Province and its composite subprovinces. 2-10
Figure 2.2. The subprovinces of the central Superior Province with distinctive lithological ..... 2-11
Figure 2.3. The Abitibi greenstone belt in the Abitibi Subprovince. 2-12
Figure 2.4. Metamorphic isograds in the Rouyn-Noranda region of the SAGB. 2-13
Figure 2.5. Tectonic map of the Rouyn-Noranda region. 2-14
Figure 2.6. Geology of the Aldermac Mine area. 2-15
Figure 2.7. General geology of the Aldermac area according to: (A) Ambrose and Ferguson.... 2-16
Figure 2.8. A schematic cross-section of the volcanic complex at Aldermac. 2-17
Figure 3.1. Diagrammatic representation of idealised lineations (L) and foliations ..... 3-35
Figure 3.2. Histograms of modal content of feldspar megacrysts estimated from hand samples. 3-36
Figure 3.3. Ternary plots of the recalculated matrix content of: (A) BPS facies rocks; and .... 3-38
Figure 3.4. Ternary plots of the recalculated matrix content of: (A) PAS facies rocks; and .... 3-39
Figure 3.5. Frequency rose diagrams for the orientation of dikes found within the SIC and .... 3-40
Figure 3.6. Frequency rose diagrams for the orientation of all of the structural features...... 3-42
Figure 4.1. Textures and fabrics found in dikes, which are commonly interpreted as flow .... 4-23
Figure 4.2. Diagrammatic representation of idealised lineations (L) and foliations, ..... 4-24
Figure 4.3. Frequency rose diagrams for the orientation of SPO foliations found within ..... 4-25
Figure 4.4. Variations in margin parallel shape preferred orientation within syenite/trachyte ..... 4-26
Figure A3.1. Frequency rose diagrams for the orientation of SPO foliations tested in..... A3-6
LIST OF MAPS

Map 1.1. Geology of the Alderman Mine Area. (see back pocket)
Map 1.2. Detailed Geology of the Mill Hill Exposure, Alderman, Quebec. (see back pocket)
Map 1.3. Detailed Geological Map of the Lucky Swine Outcrop. (see back pocket)
Chapter I

CHAPTER I: GENERAL INTRODUCTION

INTRODUCTION

This thesis reports on a petrologic, petrographic, and structural study of the Aldermac Syenite Igneous Complex (SIC), and of the related syenite/trachyte dikes that radiate from the complex into the surrounding host volcanic rocks.

The Aldermac SIC is located within Archean volcanic rocks of the Abitibi greenstone belt, approximately 16km west-southwest of Rouyn Noranda, in northwestern Quebec, Canada. Both the SIC and the radiating dikes are generally characterised by a significant content of spectacular primary igneous megacrysts of both feldspar and mafic minerals, that often exhibit a strong and well displayed shape-preferred orientation (SPO). It is therefore possible to perform in situ field assessment of SPO fabrics, which permits flexible sampling decisions. Many rock outcrops with vertical faces also provide the opportunity to assess rock fabrics in three dimensions. The Aldermac SIC provides a natural laboratory, and therefore unique opportunity, for a comprehensive study of textures and fabrics in igneous rocks, coincident with larger scale studies of intrusion geometry and morphology. The main objectives of the study were threefold:

1. To examine the Aldermac rocks in thin section, outcrop, and map scales to determine what their mineralogies, related textures, and fabrics could tell us about their petrologic evolution.

2. To examine the fabrics in thin section, outcrop, and map scales and determine their genetic relationships (if any) to the intrusion morphology and emplacement history in the SIC and the radiating dikes.

3. To test how the fabrics in the intrusive rocks compare with current models of magma flow and fabric acquisition.

THEORETICAL BACKGROUND

The determination of magma flow direction and type is an essential component in the interpretation of the intrusion mechanisms of igneous bodies (Rickwood, 1990; Smith et al., 1993). Igneous rocks can record an extended history of flow styles and magma strain, related not only to changes in magma rheology and supply (e.g. magma pulsing, multiple
injection, and changes in magma transport direction) (Paterson et al., 1989; Shelley, 1985; Philpotts and Asher, 1994), but also to the constraining relationships of intrusive emplacement such as the stress state of the surrounding rocks, space problems etc. This record may be continuous or it may only record certain events in the evolution and transport history of the magma. It is possible that textures and/or fabrics may reflect only the most recent stages in the evolution of a rock. For example, as an igneous body nears 'thermal death', near solid state flow combined with stress effects of nearby thermal expansion/compression could partially or completely overprint textures and or fabrics left by previous rheologic conditions. A model of constant, unidirectional flow of a viscous magma, and subsequent uniform freezing (with preservation of that flow regime), is likely to be insufficient in explaining the textures and fabrics found in many igneous bodies. In the absence of useful unidirectional flow indicators such as drag folds, broken and sheared phenocrysts, etc., interpretations of the history of suspension-like flow of magma are commonly based on fabrics defined by the shape-preferred orientations (SPO) of primary igneous minerals. Current quantitative models for the acquisition of SPOs invoke non-interfering "Jeffery-style" rotation (Jeffery, 1922) of rigid particles, in a viscous suspension undergoing homogeneous two-dimensional flow (e.g. Fernandez, 1987; Ildefonse et al., 1992; Tikoff and Teyssier, 1994). Highly developed SPOs, the effects of high solid contents, and phenomena involving near solid-state stress effects on the cooling magma are not accommodated quantitatively in these basic models.

A successful study and interpretation of the emplacement history of an igneous body, requires a synthesis of careful consideration of its intrusion relationships with host rocks and or other local intrusions, as well as careful descriptive recording of any textures and fabrics found within the rock.

The excellent and easily observable mineralogies and SPOs in the Aldermac SIC and its related dikes permit a synthesis of the intrusive histories of its various components and of their fabric. The observations provide useful constraints on models of SPO fabric acquisition in sheeted bodies.
ALDERMAC STUDY AREA

Brief History
Located within the Rouyn Noranda mining camp in Quebec, Canada, the Aldermac SIC and its southern contact with the host volcanics is the site of the Aldermac copper deposit and the former Aldermac Mine, which operated from 1931 to 1945. The deposit name is derived from the names of the two prospectors who first staked the claim in 1923: W. Alderson and A.A. MacKay (Hunter and Moore, 1983). It is considered to be the first deposit in the history of the Noranda mining camp to be discovered by geophysics, a dip-needle survey in 1925 (Boldy, 1979). Total production for the mine yielded 2,091,571 tons of ore, breaking down into 30,845 tons of copper, 389,100 ounces of silver, and 10,675 ounces of gold (Hawley, 1948, in Hunter and Moore, 1983). Extensive mapping by Ambrose and Ferguson (1945) and Hunter (1979; in Hunter and Moore, 1983), has primarily concentrated on the stratigraphy of the volcanic rocks that host the SIC and its related dikes. Work by Gunning (1927) reviews the complex nature of the SIC and the mineralogical curiosities that are found within.

General Geology
The general stratigraphy in the Aldermac Mine area consists of a roughly east-west trending, chemically bimodal suite of intercalated mafic to felsic flows (basalts, andesites, and rhyolites), pyroclastics, and related subvolcanic bodies (Figure 2.6). This stratigraphy is cut by:

1. Archean gabbros.
2. A large north south trending syenite intrusion (the SIC) and related dike swarm.

The Aldermac SIC consists of a complex intrusion, composed of multiply intruded sheeted bodies of varying mineralogy and textures, and a surrounding swarm of petrogenetically related dikes. Most of these rocks contain spectacular primary igneous feldspar megacrysts that exhibit strong shape-preferred orientations.
ANALYTICAL METHODS

Petrologic and structural analyses were conducted on the rocks forming the Aldermac volcanic pile, the SIC, and the dikes found in the volcanics. Field mapping at scales of 1:5000 and 1:500, and sample collection, was conducted over a period of 11 weeks, during the months of May through August 1996. Mr. Mike Thompson assisted in the field and, as a B.Sc. thesis project, also carried out a geochemical study of the area, in collaboration with Dr. M. P. Gorton of the University of Toronto. Dr. P. -Y. F. Robin visited the field area in May 1996 and July 1996. Dr. M. P. Gorton visited the field area in July 1996.

All major and minor rock types forming the SIC and dikes, were sampled and catalogued, culminating in a subclassification of igneous facies based on mineralogical mode, granularity and mineralogical textures (mutual relationships of grains). Petrographic analysis of over 70 thin sections was augmented by preliminary electron microprobe analyses using Electron Diffraction Scatter (EDS) methods (Dr. C. Cermignani) and applied to further refine and confirm field classification and mapping.

Structural mapping included orientation measurements of joints, veins, dikes, contacts, faults, bedding, and mineral defined SPO fabrics (lineations and foliations). Further analysis of SPO fabrics was conducted on selected exposures and included investigation of microtextures in thin section. Structural orientation data was plotted and analysed using the Spheristat 2.1 computer program.

OUTLINE OF THESIS CHAPTERS AND RATIONALE FOR ORDERING

Results of this analysis are presented in five chapters:

Chapter I

This chapter introduces the thesis topic by briefly discussing the theoretical background involved in the study of igneous related fabrics and their origins. An overview of the field and laboratory analytical methods is presented, and the contents of each chapter are also summarised.
Chapter II
This chapter provides a geological background of the region, with a progressive focus on the Aldermac Mine area. Results of field mapping are discussed including a brief familiarisation with the map pattern of the SIC, its related dikes and the host volcanic pile.

Chapter III
This chapter provides detailed petrologic and petrographic descriptions and characterisations of all of the rocks found in the Aldermac Mine area. Eleven syenite facies are recognised based on analyses of modal mineralogy, crystallinity, granularity, and mutual relationships between grains (where relevant to the identification or classification of a particular facies). The unique mineralologies and textures of each facies indicates definite, but not understood, petrologic processes in one or more underlying magma chambers. The great variability in modal fractions within each facies indicates that there must have been extensive fractionation between crystals and remaining liquid up to the end of in situ crystallisation. Occurrences of rocks of each facies type are reported with reference to the newly compiled maps. The exposures of the SIC indicate that it was emplaced as a large number of variously oriented vertical sheets, rather than as a single intrusion. Any examples of SPO fabrics visible in hand sample and/or thin section microanalysis are also reported in this chapter.

Chapter IV
This chapter is includes a detailed analysis of the SPOs and SPO defined fabrics found within the intrusive rocks at Aldermac. Foliations and lineations are commonly parallel to the intrusive contacts of their tabular host units. But it can also outline buckle folds, shear zones and circular patterns (particularly in dikes). The SPO is often very strong, and, combined with the high modal megacryst content, is incompatible with current Jeffery-style tumbling of crystals in a viscous matrix undergoing shear deformation. The circular patterns record the fact that at some (presumably late) stage, magmatic flow proceeded along discrete linear channels, rather than as two-dimensional ‘plane flow’. It is proposed that the SPOs preserved in dikes and other tabular bodies of syenite in the SIC may
record a progressive history of freezing of the magma in these sheets, and that they are
due to a combination of processes inhibiting the rotation of the megacrysts and of late
stage extrusion of the residual melt (‘filter-pressing’). ‘Rotation inhibitors’ include tiling,
and more generally, sticking of the megacrysts to the current margin of the active flow,
and high densities of megacrysts within the flow.

Chapter V
This chapter summarises the main conclusions reached in the discussions found in the
individual chapters. It provides a synthesis of the descriptive and interpretative
information presented in an attempt to rationalise the emplacement history of the
Aldermac SIC and its related dikes.
CHAPTER II: GEOLOGICAL SETTING

INTRODUCTION

The Aldermac Syenite Igneous Complex (SIC) and its associated dikes are intruded into the Blake River Group volcanics, which underlie most of the Rouyn Noranda Mining Camp, Quebec, Canada. The Blake River Group volcanics are one of five main divisions of supracrustal rocks that make up the Southern Abitibi Greenstone Belt in western Quebec; part of the large Abitibi subprovince of the Archean Superior Province. The following is a review of the regional geology with a progressive focus towards the rocks of the Aldermac Mine site. A brief overview of the map pattern of the SIC and its related dikes is also included.

REGIONAL GEOLOGY

Superior Province

Canada’s Archean Superior Province is the largest and most continuously exposed craton in the world. It is separated from its neighbouring Archean blocks by the Appalachian orogen and Proterozoic orogens (Thurston, 1991), and is itself composed of multiple fault-bounded linear belts (Figure 2.1). Each of these individual belts or subprovinces is characterised by a distinctive assemblage of protoliths (Figure 2.2), metamorphic facies, structures and ages (Thurston, 1991; Jackson et al., 1994). Belt types include:

1. clastic metasedimentary belts of granulite or amphibolite facies (i.e. Quetico, Opatica and Pontiac Subprovinces),
2. amphibolite grade gneiss belts intruded by tonalite granodiorite and syenite (i.e. English River Subprovince),
3. plutonic belts consisting of gneissic tonalite and massive granitoid plutons (i.e. Winnipeg River, Berens River and Biensville Subprovinces), and
4. granite-greenstone belts composed of low grade metavolcanic and metasedimentary rocks, cut by granitoid plutons (i.e. Abitibi, Wabigoon, Uchi, Sachigo and Wawa Subprovinces) (Thurston and Chivers, 1990).

The large granite-greenstone belts suggest formation of the Superior Province in a primarily oceanic setting, while the metasedimentary belts located to the south are
thought to represent associated passive margin sediments or accretionary complexes (Williams, 1990; Corfu and Davis, 1992). These supracrustal assemblages were coalesced into fold and thrust belts and juxtaposed along regional faults, which now form the subprovince boundaries (Williams, 1990; Corfu and Davis, 1992). The dominant period of magmatism appears to have occurred at 2770-2600 Ma, preceded by a minor period of magmatism at 3200-2800 Ma (Corfu and Davis, 1992).

Abitibi Subprovince
The Abitibi Subprovince (Figures 2.1 and 2.2) is a granite-greenstone terrane whose dominant period of magmatism has been dated around 2760-2660 Ma (A.R. Cruden, Pers. Comm., 1998). Its western boundary is defined by the Kapuskasing Structural Zone, which is a Neoarchaean-Paleoproterozoic intracratonic overthrust (Percival and Card 1983, 1985; Jackson and Fyon 1991; Halls and Zhang, 1998). The southern and eastern boundary of the Abitibi Subprovince is defined by the contact with the Huronian Supergroup (a Paleoproterozoic rift and passive margin sequence), the Neoarchean Pontiac Subprovince, and the high grade gneisses and granitoids of the Grenville Province (Jackson and Fyon 1991). The Subprovince is subdivided into several supracrustal-dominated domains, or greenstone belts:

1) the Abitibi greenstone belt,
2) the Batchawana greenstone belt,
3) the Benny, Hutton and Parkin greenstone belts,
4) the Temagami greenstone belt (Jackson and Fyon 1991).

The belts listed above in items 2 through 4 are areally minor and occur to the South of the Abitibi greenstone belt; they are not considered further here. The Abitibi greenstone belt (AGB) is unique in that it is:

1) the largest plutonic-volcanic belt in the Superior Province,
2) the largest greenstone belt in the world,
3) low in metamorphic grade,
4) composed of a high ratio of supracrustal to intrusive rocks, and
5) it contains abundant and varied mineral deposits (Jackson and Fyon 1991).
The AGB is traditionally subdivided into a northern and southern region (Dimroth et al., 1982; 1984). The northern region (Figure 2.3), or Northern Abitibi Greenstone Belt (NAGB), is characterised by abundant tonalite-trondhjemite-granodiorite intrusions, large anorthosite complexes, a lack of ultramafic flows, and greenschist or higher grade regional metamorphism (Jackson and Fyon, 1991). By contrast, the Southern Abitibi Greenstone Belt (SAGB), is characterised by fewer granitoid intrusions, an abundance of ultramafic flows, and greenschist or lower facies metamorphism (Dimroth et al., 1983). The remainder of this summary is mainly concerned with the geology of the SAGB in Western Quebec.

The Southern Abitibi Greenstone Belt (SAGB) and the Rouyn Noranda Mining Belt

In Quebec, the supracrustal rocks of the SAGB are subdivided into five volcanic groups (Figure 2.5):

1) The Hunter Mine Group, which is composed of 2730-2713 Ma bimodal, calc-alkaline assemblages (Corfu et al., 1989).

2) The Stroughton-Roquemaure and Malartic groups, which overly the Hunter Mine Group and are composed of tholeiitic and komatiitic volcanics younger than 2714 Ma (Corfu et al., 1989).

3) The Kinogevis Group, which overlies the Stroughton-Roquemaure and Malartic groups, and is composed of tholeiitic basalts intruded by concordantly metamorphosed gabbroic dikes and sills (Dimroth et al., 1983).

4) The Blake River Group, composed of 2703-2698 Ma bimodal volcanic rocks, and intruded by a trodjhemitic-tonalitic suite. A later discordant granodioritic-syenitic suite penetrates the group and is itself unmetamorphosed (Dimroth et al., 1983). The Blake River Group is bounded by the Porcupine-Destor deformation zone to the north, and to the south by the Larder-Cadillac shear zone (Dimroth et al. 1983).

5) The Timiskaming Group, composed of 2690-2685 Ma shoshonitic, trachytic and pyroclastic flows and alluvial-fluvial sedimentary assemblages. These rocks are intruded by 2680 Ma syenitic intrusions (Corfu et al. 1989).
Regional deformation occurred prior to and after formation of the Timiskaming alluvial fluvisal sedimentary rocks and associated alkalic metavolcanic rocks. Most supracrustal rocks within the SAGB have been metamorphosed to subgreenschist to greenschist facies, only rising to amphibolite facies metamorphism in regions adjacent to some intrusions (Figure 2.4) (Jolly, 1978; Dimroth et al., 1983; Powell et al., 1992).

The geology of the Noranda region (including Aldermac) consists of mafic and felsic volcanic rocks and intrusions of the upper portion of the Blake River Group (Figure 2.5). The rocks are a typically subaqueous basalts, rhyolites, andesites and gabbros, and have been divided into five extensive intercalated felsic formations, cyclically separated by mafic flows (Spence 1967, Baragar 1968, Spence and de Rosen Spence 1975).

While most of the Abitibi belt typically exhibits greenschist facies metamorphism and tight isoclinal folding of its volcanic successions (Goodwin and Ridler 1970; Dimroth et al., 1993), the Noranda area subgreenschist (prehnite-pumpellyite) facies volcanics (Jolly 1978) are only gently folded (Hunter 1983), forming a large east trending and east plunging anticlinorium. Spatially related faults and felsic intrusives occur throughout the area.

**Topography and Access**

The regional topography of the Abitibi subprovince is generally quite flat, but the Rouyn Noranda area is characterised by an abundance of low ridges and hills, which are dominantly separated by lakes, swamps or bogs. Some localised regions including the Collines Kekeko, Mont Kanasuta, and Colline Cheminis areas display an even more striking relief. Outcropping rock generally accounts for approximately 20% percent of the regional surface area (Jones, 1989).

In the Aldermac area the topography is dominated by raised ridges, composed of weathering resistant volcanics, surrounding swampy lows, which mapping reveals to be preferentially weathered syenite porphyry. The volcanics on the ridges are well exposed, comprising approximately 60% of the local topographic surface, but the syenites are very poorly exposed. Outcropping rock within low area only covers about 5% of the surface area. Significant deposits of glacial till and mine tailings also cover portions of the mapping area.
Chapter II

GENERAL GEOLOGY OF THE ALDERMAC PROPERTY

The geologic setting of the Aldermac Mine area reflects an extended history of extrusive and intrusive activity punctuated by intermittent faulting and hydrothermal ore-forming processes (Hunter and Moore, 1983). The stratigraphy is composed of a roughly east-west trending, chemically bimodal suite of intercalated mafic to felsic flows (basalts, andesites, and rhyolites), pyroclastics, and related subvolcanic bodies (Figure 2.6). This stratigraphy is cut by: (1) Archean gabbros; (2) a large north south trending syenite intrusion and related dike swarm; and (3) post-Archean diabase dykes (Hunter and Moore, 1983).

Volcanics

Field mapping of the Aldermac Mine site reveals a horseshoe shaped ridge composed of felsic, intermediate and mafic volcanics hosting an elongate syenitic intrusion. Much of the volcanic pile is block faulted, and individual volcanic horizons cannot be traced for more than 150 m (Hunter and Moore, 1983). Those that are traceable, typically strike around 075° in volcanics to the east of the syenite body, and around 110° to the west of the syenite. All volcanic horizons dip between 30° and vertical, with dips to the north or south depending on location. Ambrose and Ferguson (1945), and Hunter and Moore (1983) also report local oppositions in younging directions, thought to be due to opposing directions of rotation of the various fault blocks (Hunter and Moore, 1983). These oppositions were not detected by the author.

The mafic and felsic volcanic rocks in the Aldermac area have undergone varying degrees of silicification. This is most pronounced in the basalts and andesites, and considerably less so in the rhyolites. While macroscopic primary igneous textures in some occurrences allow for distinction of rock types at outcrop scale, many volcanic occurrences can only be field mapped as ‘green intermediate volcanics’. Only through careful petrographic and geochemical analysis can the distinction between the three major volcanic rock types be made (Hunter and Moore, 1983). This is evidenced in Hunter’s (1979, in Hunter and Moore, 1983) re-mapping of the original work of Ambrose and Ferguson (1945) (Figure 2.7). This reclassification of Aldermac volcanics is
supported by Cattalani et al.'s (1995) geochemical analyses. For the purposes of this study only those horizons which were detectable in the field are shown on the included Map (Map 1.1). For more detailed mapping of the Aldermac volcanics see Hunter and Moore (1983) and Cattalani et al. (1995).

**Syenite Intrusive Complex (SIC)**

Lying at the centre of the Aldermac mine property, in a topographic low, is a ca. 10 km² syenite intrusion, locally known as the Syenite Igneous Complex (SIC). It is an elongate stock-like body with an approximate north south length of 6 km, and an east west width of 1.6 km (Map 1.1). It cuts all of the local volcanic rocks, and is in turn cut by a later, post Archean diabase dyke. The entire complex is interpreted as a heterogeneous series of intrusions (Gunning, 1927), from a shallow subvolcanic reservoir, rather than a homogeneous unit or diapir; and this interpretation is confirmed and amplified in the present study. No volcanic equivalents have been found in situ (Hunter and Moore, 1983), although there are abundant alkalic volcanic fragments in the overlying glacial till. While no age date exists for the SIC, the neighbouring Clericy Pluton (see Figure 2.4) is petrographically similar and has a determined age of 2684±1 Ma (U-Pb zircon) (J.K. Mortenson in Bourne and L’Heureux, 1991). It has been proposed that these syenites and petrographically and geochemically similar rocks in adjacent portions of Ontario, i.e. the Otto Stock at 2680±1 (A.R. Cruden, Pers. Comm., 1998), are all part of an ultrapotassic igneous province, emplaced over a time span of approximately 10 Ma (Bourne and L’Heureux, 1991).

The SIC is poorly exposed, but detailed mapping of outcrop-rich regions (conducted as part of this study and reported in Chapter III) indicates that it is composed of multiple intrusions of a varying suite of mafic through felsic syenite facies. Intrusion styles include plugs, dikes, sheeted dikes, and large tabular bodies, all of varying orientation but with roughly vertical dips.

**Syenite/Trachyte Dikes**

Many of the dikes found at Aldermac contain matrix mineralisation that is aphanitic. Thus the term trachyte (the aphanitic compositional equivalent of syenite) will be used...
here to refer to these dikes, following the IUGS (1976) recommendation of names for aphanitic and phaneritic igneous rocks. Furthermore, for the purposes of this study, those igneous bodies that possess high aspect ratios contain dominantly aphanitic matrix mineralogies, and cut their host rocks discordantly will be classified as dikes. This includes dikes found within the SIC, and dikes intruded into the volcanic pile. Multiply intruded dikes (sheeted dikes) and irregular tabular bodies found in the SIC will only be treated under discussions of the SIC.

Numerous syenitic and trachytic dikes radiate from the SIC into the surrounding host volcanic pile (Map 1.1). These are concentrated around the southeastern, southern, and southwestern margins of the complex; numerous dikes to the northwest have been reported by Gunning (1927). Dikes can vary in thickness between 5 cm and 10 m, and can be traced on individual outcrops up to 100 m, but outcrop to outcrop correlations are rare. Most of the dikes are found near the margins of the SIC, including several which contact the complex at the Mill Hill location (Maps 1.1 and 1.2).

As detailed in Chapter III, all dikes can be broken down into several petrographic facies. Some of these facies are mineralogically similar to rocks found in the SIC, but are distinguished by different intrusion morphologies and/or different mineralogical and petrographic textures. Other facies occur as dikes in both the SIC and the surrounding volcanics. This phenomenon is more common in occurrence with the later more felsic facies types.

**Other Petrologic Features**

Postdating the SIC and syenite dikes, milky quartz veins ranging from 0.5 cm to 10 cm wide are found within the SIC and surrounding volcanics. These are in turn crosscut by diffuse stringer veins of fibrous blue amphibole. Also post-dating the intrusion of syenite rocks, is a large diabase dike, the ‘older gabbro’ of Gunning (1927). This approximately twenty-metre wide dike cuts across most of the Aldermac map area as a pair of en echelon segments trending 105° and 130° respectively. The timing relationship between this diabase and the quartz and blue amphibole veins is not clear. Previous maps of the Aldermac area include several lamprophyre dikes. Petrographic analysis reveals several of these to be extensively altered syenite porphyry dikes. An east west trending, sill-like
Chapter II

body located south of Mackay Lake, does possess the geochemical signature of a lamprophyre (Thompson, 1997).

**Emplacement History and Igneous Environment**

The presence of local faults and the exposed stratigraphy of the volcanic pile indicate that local and/or regional structural episodes have disturbed the original orientation of the volcanic beds. This raises the question of how do the current orientations of the SIC and its dikes relate to their original intrusion orientations? Two main end-member scenarios can be envisioned for the geologic history of the rocks that form the Aldermac Mine site:

*Model 1. Pre-Rotation Emplacement. The SIC was emplaced as a series of sills and dikes.*

Dikes intruded the overlying volcanic pile in a fan-like fashion. The whole volcanic pile was then rotated approximately 90°, about a single horizontal axis, to its current position, yielding a longitudinal section through the complex and the volcanics.

*Model 2. Post-Rotation Emplacement. The volcanic pile was faulted and rotated about a single horizontal axis approximately 90° to its current position. This was followed by emplacement of the SIC as a series of vertical tabular bodies, i.e. sheeted dikes, dikes, etc.; and emplacement of the surrounding dike swarm. The current level of erosion yields a latitudinal cross-section of the complex.*

Hunter and Moore (1983) favour a variation of the first model in which the emplacement of the SIC and its related dikes occurred syn-volcanically, with local rotation of several fault blocks rather than a single regional rotation episode. Based on geochemical and structural mapping of the Aldermac Mine site, Hunter and Moore (1983) provide an interpretation of the volcanic history and environment at Aldermac (Figure 2.8). According to these authors, major igneous and structural episodes at the Aldermac Mine site include (please refer to Figure 2.8):

1. Concurrent eruption of intercalated mafic and felsic volcanic rocks, i.e. andesite, rhyolite, and basalt (MV1, R1).
2. Massive sulphide deposition (shaded and cross hatched-areas) occurs during a hiatus in felsic volcanism, recorded by tuffaceous exhalites in some localities.
3. Later generations of rhyolite (R2) are deposited as lava domes.
4. Sills and dikes of gabbro (G) are intruded.
5. Rotation and displacement of fault blocks occurs.
6. Area may have been covered in basaltic flows (MV2).
7. Syenite Igneous Complex (S) and associated radial dikes are intruded. Pre-existing weak zones such as faults may have channelled magma.
8. Further readjustment of pre-existing fault blocks may also have occurred during emplacement of the SIC.
9. Erosion of alkalic volcanics (AV) (extrusive SIC equivalents?) and later volcanics to present level.

The original environment may have been a submarine graben or trough shaped caldera (Hunter and Moore, 1983).
Figure 2.1. The central Superior Province and its composite subprovinces. The Abitibi Subprovince is shaded (modified from Jackson and Fyon; 1991).
Chapter II

LEGEND

- Proterozoic, Phanerozoic rocks
- Subprovince boundary

ARCHEAN SUBPROVINCE TYPE

- Plutonic
- Volcano-plutonic
- Metasedimentary
- High-grade gneiss

Figure 2.2. The subprovinces of the central Superior Province with distinctive lithological belt types indicated (from Card; 1990).
Chapter II

Proterozoic and Phanerozoic rocks
High-grade Archeon metasedimentary rocks / Granitoids (P= Pontiac metasedimentary belt)
Archean granitoid rocks in Abitibi greenstone belt
Granitoid rocks of Opatica Subprovince
Gneisses and Granitoids (KW= Kapuskasing Structural Zone and Wawa gneiss terrane)

Supracrustal rocks of southern Abitibi greenstone belt
Supracrustal rocks of northern Abitibi greenstone belt
Boundary between southern and northern Abitibi greenstone belt
Thrust / Reverse fault

Figure 2.3. The Abitibi greenstone belt in the Abitibi Subprovince. The division between the northern and southern Abitibi greenstone belt (Dimroth et al.; 1982) is indicated (figure from Jackson and Fyon; 1991).
Figure 2.4. Metamorphic isograds in the Rouyn-Noranda region of the SAGB. Intrusions are: F = Flavrian; P = Powell; D = Dufault; C = Clericy; M = Montsabrais; A = Aldermac (modified from Dimroth et al.; 1983).
Figure 2.5. Tectonic map of the Rouyn-Noranda region, highlighting the geology of the Blake River Group. The Structural Sections can be found.
Table of Formations

**Proterozoic:**
- Diabase
- Cobalt Group (conglomerate, arkose, and mudrock)

**Archean:**
- Timiskaming Group (conglomerate, sandstone)
- Kawagama Group (conglomerate, sandstone)
- Cadillac Group (conglomerate, sandstone)

**Blake River Group:**
- Granite, granodiorite, associated gabbro and diorite
- Volcanic clastites (andesitic)
- Rhyolitic volcanoclastites and rhyolite porphyry
- Mafic and intermediate lavas
- Varicolored ferruginous basalts
- Mafic Group (differentiated volcanic rocks)
- Kinogamis Group (basalts with minor rhyolite)

**Major Structures:**

<table>
<thead>
<tr>
<th>CS</th>
<th>Clericy syncline</th>
<th>MLA</th>
<th>Manillac Lake antiform</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLA</td>
<td>Bayard Lake anticline</td>
<td>DstS</td>
<td>Dupuis Lake synform</td>
</tr>
<tr>
<td>FBS</td>
<td>Fabie Bay syncline</td>
<td>TLA</td>
<td>Tremo Lake antiform</td>
</tr>
<tr>
<td>KRA</td>
<td>Kasasuta River anticline</td>
<td>RLS</td>
<td>Rouyn Lake synform</td>
</tr>
<tr>
<td>ALA</td>
<td>Adeline Lake anticline</td>
<td>MAJOR FAULTS</td>
<td></td>
</tr>
</tbody>
</table>

**D2 Structures:**
- HuCF | Hunter Creek fault |
- MLA | Nor Lake antiform |
- DplS | Dunat Lake synform |
- FLA | Flavian Lake antiform |
- DILS | Dufaut Lake synform |

**Legend:**
- Synclinal and anticlinal structures, overturned
- Synformal and antiformal structures
- Strike and plunge of fold axis
- Strike, dip, and top of bedding (normal)
- Strike, dip, and top of bedding (overturned)
- Strike and dip of first schistosity
- Strike and dip of cleavage
- Strike and dip of kink band
- Major fault (a) normal
- Major fault (b) reverse
- Major fault (covered)
- Sinistral shear
- Geological contact
- Structural section
- Township limit
- Province limit
- Provincial road with number

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The Structural Sections can be found in (Hubert et al., 1984). Figure modified from Hubert et al. (1984).
Figure 2.6. Geology of the Aldermac Mine area. This map covers the southern portion of the study area indicated on Figure 2.5. (from Hunter and Moore, 1983).
Figure 2.7. General geology of the Aldermac area according to: (A) Ambrose and Ferguson (1945) and (B) Hunter and Moore (1983). This figure highlights the differences between previous workers interpretations of the composition of the volcanics. Hunter’s interpretation, based on geochemical mapping is supported by Cattalani et al. (1995). The author confirms the locations of the syenite and the late diabase dike. For more detailed mapping of the syenite intrusion and related dike swarm see Chapters II and III.
Chapter II

Figure 2.8. A schematic cross-section of the volcanic complex at Aldermac. The sections are oriented roughly north-south and pass through the old Aldermac Mine (see Map 1.1). Three stages in the evolution of the volcanic complex are shown (see also main text):

A: A rhyolite dome (R1) is formed in a volcano-tectonic depression of intercalated mafic/felsic volcanic beds (MV1).

B: Post ore (shaded and hatched areas) events include rotation and displacement of fault blocks, inundation by late mafic volcanics (MV2), late rhyolite extrusion (R2), and intrusion of gabbros (G).

C: Intrusion of the Syenite Igneous Complex (S) and its related dikes, which feeds lava to form alkaline volcanic (AV) edifices. The horizontal line indicates the current level of erosion.

Figure from Hunter and Moore (1983).
Chapter III

CHAPTER III: PETROGRAPHIC AND PETROLOGIC ANALYSIS OF THE ALDERMAC MINE AREA

ABSTRACT

Results of detailed mineralogical, textural, and fabric analyses indicate that there is a definite sequential evolution of the magma that is host to the feldspar megacrysts, and which forms the rocks of the Aldermac Syenite Igneous Complex (SIC) and its related dikes. At the level observed, the pluton demonstrates a map scale lithological heterogeneity, highlighted by the crosscutting relationships of various syenitic and granitic ‘facies’. These facies are defined primarily by their matrix compositions and associated mineralogical textures. Heterogeneities can also be observed at outcrop scale, where multiple intrusions of a single facies type may differ only in modal volume percentage of feldspar megacrysts, or variations in matrix composition. Similar modal variations may also occur at hand sample and thin section scale. These heterogeneities indicate a fractionation of the magma at all scales. Initial fractionation processes probably occurred in a subjacent magma chamber prior to transport of magma to the current location, yielding the wide variety of compositional facies. These processes were complemented by in situ filter pressing of the magma during various stages of cooling, yielding significant map, hand, and thin section scale heterogeneities within individual facies.

INTRODUCTION

This chapter presents a detailed study of the mineralogical content, associated textures and fabrics of the rocks that form the Aldermac Syenite Igneous Complex (SIC) and its related dikes. It provides petrographic descriptions at thin-section, hand sample, and map scale, of all of the rocks observed in outcrop in the Aldermac Mine mapping area. Structural information, including crosscutting relationships between rock types and orientations of individual bodies of rock are also reported with reference to the compiled maps.

The rocks which make up the SIC and its associated dikes exhibit a map scale heterogeneity, highlighted by the crosscutting relationships of numerous individual
igneous bodies; each belonging to a distinctive igneous ‘facies’ defined by unique mineralogical contents and textural characteristics. Although the modal amounts of individual minerals can vary widely (even within an individual facies), all of the rocks of the SIC and its associated dikes are characterised by an alkali feldspar content that makes up at least two thirds of all the feldspar present. The SIC is dominated by megacrystic syenites (sensu stricto) (see Appendix A4 for a review of the geochemistry and mineralogy of syenites). Many of the associated dikes found within the SIC and intruded into the surrounding volcanic rocks are also megacrystic syenites, but most of these are their aphanitic equivalents, i.e. porphyritic trachytes. The feldspar megacrysts (porphyroclasts) often exhibit a strong and well displayed shape-preferred orientation (SPO) fabric. The megacrysts and matrix minerals also exhibit textures representative of various stages in the growth history of the rocks.

**Textures and Fabrics in Igneous Rocks**

From the point of their inception, most igneous bodies will have undergone a continuum of processes, that include the initial transport of a liquid-crystal mixture, an incremental solidification and fractionation of the magma, and possible subsequent metasomatic, deuteric, and/or metamorphic alteration. Some useful indicators of the processes that occurred during magma formation and transport are textures and fabrics preserved in those rocks. Although not universal in the relevant literature, it is useful here to make the distinction between texture and fabric. Textures are defined here as those geometrical characteristics of the component grains in a rock (MacKenzie *et al.*, 1982) that are thought to record the igneous growth history of these grains. They include the following properties:

1. **Granularity**, i.e. the absolute and relative sizes of component crystals, e.g. porphyritic, seriate, and aphanitic textures.
2. **Crystal shapes or habits** e.g. Baveno habit; and the quality of development of crystal faces, e.g. anhedral, subhedral, euhedral.
3. **Mutual relations between crystals** e.g. poikilitic and Rapakivi textures.

Although the third property listed above (mutual relationships between crystals) arguably covers the shape-preferred arrangement of grains, (i.e. a trachytic arrangement of
elongate megacrysts), in this analysis these types of crystal relationships or patterns are defined and treated separately as fabrics. These record the deformation of the magma or rock and its constituent grains. For the purposes of this study fabrics are thus defined here as the collective ordering (or lack of ordering) of the constituent grains in a rock in relation to each other, as defined by shape-preferred orientations (SPOs). Common SPO defined fabrics include lineations and foliations defined by the preferred orientations of biaxial and/or triaxial mineral grains (Figure 3.1). Fabrics visible in thin section and hand sample are presented here as part of the descriptions of facies. Outcrop and map scale treatment and discussion of fabrics are the focus of Chapter IV.

The textures associated with the various minerals present in the Aldermac Mine site intrusive rocks, form an integral part of the facies classification scheme developed in this study. A definite sequential evolution of the magma is indicated by the crosscutting relationships of numerous intrusive bodies formed from these facies. Further evidence of the evolution of the magma at Aldermac is seen in the outcrop, hand, and thin section scale heterogeneities present. Modal variations and textural differences indicate that the magmas that now form the Aldermac SIC and its related dikes were probably affected by magma chamber fractionation, transport, and further fractionation by filter pressing.

**Methodology**

Field mapping of the southern two thirds of the Aldermac Syenite Igneous Complex (SIC) and its associated dikes was conducted at the 1:5000 scale (Map 1.1), using aerial photographs and topographic maps. Only reconnaissance mapping of the surrounding host volcanics rocks was conducted, as necessary to locate dikes. These chemically altered and macroscopically indistinguishable volcanic flows have already been mapped and described by Ambrose and Ferguson, 1945; Hunter and Moore, 1983; Cattalani et al., 1995). Detailed mapping of the Mill Hill and Lucky Swine exposures (Maps 1.2 and 1.3 respectively) was also conducted at the 1:500 scale (crosscutting dikes in volcanics and a multiple syenitic intrusion, respectively). Final maps were digitized and created using AutoCAD Release 12 and 14. All structural data was collected using a Brunton transit applying the Canadian 360° right-hand-rule convention. Over 220 outcrops were described, and mapped, including rock descriptions and collection of structural data (see
Appendix A1 for structural data). From these outcrops approximately 325 samples of volcanic rocks, SIC material and related dikes were collected.

All rock samples were catalogued and described, including approximate modal (volume) percentage of minerals present and mean grain sizes. Due to the very coarse grained nature of most rock samples in the SIC and related dikes, it was determined that the considerable time and work involved in point counting was not worth the potential gains in precision of modal estimates. Thus visual estimates of modal volumes were based on charts such as that found in Folk (1970). All modal estimates were made from exposures or cuts perpendicular to the foliation defined by the megacrysts. Approximately 70 thin sections (and complementary polished slabs) were made from representative samples (and varieties). Rock samples were sectioned perpendicular to the foliation plane. Microscopy, including complete petrographic reports (see Appendix A2), and microphotography was conducted on a Nikon Labophot-POL petrographic microscope, using standard analytical techniques (Kerr, 1977; Nesse, 1986; Shelley, 1993). Analyses of modal mineralogy, crystallinity, granularity, and mutual relationships between grains are reported, applying non-genetic descriptive terminology. (Brief descriptions of optical characteristics used to identify a particular mineral will be presented in the following text where that mineral is first mentioned). These analyses were augmented by qualitative Electron Microprobe identification using Electron Diffraction Scatter (EDS) at the Department of Geology, University of Toronto (Dr. C. Cermignani). Using the rock and thin section descriptions, the field classification scheme was refined, and the various rocks were grouped into a set of eleven distinct facies defined by distinctive mineralogical contents and textures. These facies are presented in detail in the main body of this chapter. Due to the wide variation in modal amounts of feldspar megacrysts in some of the rocks, the matrix mineralogies of some of the facies have been recalculated into three end-members totalling 100%. The three end-members are chosen based on the dominant matrix minerals. The results are plotted in ternary diagrams.

Structural information was compiled, plotted, and analysed (unweighted data values) using the Spheristat 2.1 computer program.
VOLCANIC ROCKS

At the Aldermac Mine site the volcanic pile consists of a chemically bimodal suite of intercalated mafic (basaltic to andesitic) and rhyolite flows, with pyroclastics and related subvolcanic bodies (Hunter and Moore, 1983). The rocks possess well preserved textures and structures, with the exception of those units that are in close proximity to sulphide mineralisation (Hunter and Moore, 1983).

Overall, the volcanic pile appears to be a series of roughly east-west trending volcanic flows that have been tilted to reveal their stratigraphy (Map 1.1; Figure 2.6). From detailed mapping and analysis of drill core data, Ambrose and Ferguson (1945) and Hunter and Moore (1983) concluded that most of the volcanic pile is block faulted, and that the faults truncate many of the volcanic horizons, which cannot be traced for more than 150m (Figure 2.6). Traceable beds lying to the east of the SIC, typically strike around 075°, while beds on the western side strike around 110°. The volcanic horizons dip to the north or south, between 30° and vertical. Ambrose and Ferguson (1945), and Hunter and Moore (1983) also report local oppositions in younging directions. However, in this study only one stratigraphic top indicator was found, a rip up structure in the southwest region of the map area, indicating a younging to the north (Map 1.1).

Mafic Volcanics

The mafic (basaltic to andesitic) flows are typically massive with minor amounts of vesicles present. They occur throughout the map area as relatively small interbeds in the voluminously dominant felsic volcanics (Map 1.1). Some contain preserved plagioclase phenocrysts and original cooling cracks. Local hyaloclastites, tuffs, tuff breccias and debris flows are visible, and, while the author did not locate any convincing pillow structures in the Aldermac area, they have been reported (Ambrose and Ferguson, 1945; Hunter and Moore, 1983). In thin section, plagioclase phenocrysts are seen in a microscopic mat of amphibole and feldspar microlites, with minor titanite and opaque minerals (see Appendix A2 for thin section reports). Chlorite and epidote are common alteration products, while chlorite pseudomorphing pyroxene is locally present (Hunter and Moore, 1983). Calcite and quartz amygdales are common.
**Felsic Volcanics**

The felsic rocks, typically rhyolite, are either massive and aphyric or quartz-feldspar porphyries. They occur as flows, tuffs, breccias and dikes (Map 1.1; Figure 2.6). Hunter and Moore (1983) have recognised two generations of rhyolite: the first occurs as domes, flows, tuffs and breccias; the second post-dates local sulphide deposition and occurs as dikes and sills. In thin section a variable amount of subhedral to euhedral quartz and feldspar phenocrysts are seen in a groundmass of microscopic quartz and feldspar, with titanite and opaques as accessories. Alteration products include abundant sericite, chlorite, epidote and calcite.

**Related Intrusions**

A notable porphyritic monzogabbro ("gabbro"? of Hunter and Moore, 1983) occurs as sills intruded into volcanics in the southwestern portion of the map area (Map 1.1; Figure 2.6). The rock is reddish brown on a weathered surface and a pinkish white on fresh surfaces. It is typified by equant, 1-5 mm feldspar megacrysts in a fine-grained mafic-rich matrix. The megacrysts are tightly packed together and can represent up to 80% of the mode. A typical mode consists of: albite twinned plagioclase megacrysts, 45%; tartan twinned orthoclase megacrysts, 30%; blue alkali amphibole, 20%; quartz, 3%; Fe-oxides, 2%; and trace amounts of titanite and apatite. All of the feldspar megacrysts are euhedral with slightly overgrown margins, pale pink to white, and possess irregular zoning, defined by dusty inclusions. Many of the feldspar megacrysts have outer rims free of zoning (possibly coronas of different composition) with occasional inclusions of matrix minerals. Irregular (deformed) Carlsbad twin planes are common. While the megacrysts are tightly packed together, they are rarely in grain-to-grain contact; a thin layer of mafic matrix material usually separates them. This matrix material is dominated by needles or blades of blue amphibole less than 1 mm long, euhedral iron oxides, anhedral quartz, and accessory amounts of euhedral titanite and apatite; all occurring as interstitial clots or thin layers between feldspar faces. These clots and layers have the appearance of flattened to sub-flattened cageworks of amphibole needles. The anhedral quartz appears to be a final interstitial fill in the matrix.
An east west trending, sill-like body located south of Mackay Lake (Map 1.1), possesses the geochemical signature of a lamprophyre (i.e. high alkalis and high FeO + MgO) (Thompson, 1997). This body had been mapped by previous workers as a gabbro (Hunter and Moore, 1983) and a “heterogeneous mafic rock” (Cattalani et al., 1995). The rock is geochemically unrelated to the Blake River volcanic sequence (Thompson, 1997).

**SYENITE IGNEOUS COMPLEX**

The Syenite Igneous Complex (SIC) is a petrologically heterogeneous and structurally complex pluton dominating the centre of the Aldermac Mine map area (see Map 1.1). It extends approximately 6 km North from the Aldermac Mine site, with an East-West width of approximately 1.6 km. Whole rock and trace element geochemical analysis (Thompson, 1997) indicates that these rocks are not petrologically associated with the host volcanic rocks.

The intrusion has variable texture and granularity, with rocks ranging from very fine-grained to very coarse-grained, with varying mineralogical contents, modal compositions, and colour indexes. The majority of the rocks contain alkali feldspar megacrysts whose size, form, and modal volume proportion can vary widely, not only between different rock types, but also within an individual rock type or exposure. All of these variations detail a heterogeneous complex interior composed of: parallel successively intruded sheeted-bodies, dikes, plugs and, irregular tabular bodies (Map 1.1). This heterogeneity is apparent at map scale, and in some instances outcrop, hand-sample, and thin-section scale.

While no two igneous rocks in the SIC are identical in every respect, they are grouped here into six broad syenite ‘facies’, based primarily on matrix mineralogies, modal contents and mineralogical textures. Table 3.2 lists each facies, named for its characteristic matrix mineralogical content, the facies abbreviation (as used in the remainder of the text), and the IUGS recommended (1976) name for a representative rock sample for that facies. Table 3.3 lists the ranges for modal mineral compositions (volume percentage) for the SIC facies.
Facies Variation and Timing Relationships

Based on crosscutting relationships, the earliest facies are characterised by a matrix mineral content that is typically mafic in appearance with abundant ferromagnesian minerals and no free quartz, while the latest facies have more felsic matrix minerals in the mode and locally contain free quartz (Gunning, 1927).

While this broad temporal differentiation between early mafic and late felsic facies is useful, there are no clear intersection relationships between many of the facies whose matrix mineralogies are more intermediate in character. Smaller bodies of felsic composition discordantly cutting larger mafic bodies (see Map 1.1) exhibit the only clear crosscutting relationships among the SIC facies, while the remainder of the contacts between different facies do not exhibit discordant relationships or are inferred. Thus no distinction can be clearly made in the timing of intrusion of the individual facies. As a result, facies are treated here in order from mafic rich to mafic poor modal matrix mineralogies.

General Map Pattern of the SIC and Contact Relationships

Large bodies of the various mafic rich facies dominate the complex, in the form of plugs or large sheeted dike complexes, while the younger felsic facies are voluminously less significant, and occur as smaller tabular bodies. Individual outcrops can exhibit multiple parallel intrusions of different facies, or successive parallel intrusions of rocks from the same facies, (where each individual intrusion is distinguishable by differences in mineralogical mode and/or grain size).

Contacts between the SIC and the host volcanic rocks were only found in six localities (Map 1.1). These contacts are usually sharp and no metamorphic contact aureole is visible in the volcanic rocks. On the Mill Hill outcrop (Map 1.2), a large body of mafic rich syenite is found in contact with the volcanic pile, with large (up to 1.5m) rounded rafts of volcanic rock enclosed by syenite (Plate 3.1A).

Within the SIC, visible contacts between units are sharp. These contacts can occur between units of different facies (Plate 3.1B) or multiple units from the same facies, the latter distinguishable by mineralogical characteristics (e.g. mode, grain size, etc.), and/or variations in mineral defined shape-preferred orientations. These apparently conformable
contacts can yield multiple sheeted bodies of rocks that fall within the same facies, such as those found in the vicinity of the old Aldermac mine (Map 1.1), or multiply intruded, sheeted parallel bodies of different facies (e.g. the Lucky Swine Exposure, Maps 1.1 and 1.3). Some of these large multiple intrusions are inferred to truncate other multiple intrusions at a high angle to their contacts, at a map scale (Map 1.1). This phenomenon becomes more common with later felsic intrusions, which are usually smaller tabular bodies that often cut the boundary contacts of larger mafic bodies at a high angle. These contacts often truncate individual feldspar grains within the older rocks (Plate 3.1C and D). Contact orientations between tabular bodies vary significantly within the SIC (Map 1.1).

**SIC Facies:**

*Biotite Pyroxene Syenite (BPS)*

Rocks of this areally dominant facies are composed of tabular alkali feldspar megacrysts in an aphanitic to (dominantly) phaneritic matrix of biotite and clinopyroxene (Table 3.2). In hand sample, the feldspar megacrysts generally range in size from 2 mm long to 30 mm long, with local varieties containing grains of 15 cm length or longer.

**Occurrence**

Rocks of the BPS facies appear to dominate the interior of the exposed SIC. This is the only SIC material that is observed in direct contact with the volcanic host rocks (Map 1.1). At the Mill Hill outcrop (Maps 1.1 and 1.2), BPS material was found injected into the volcanic pile as a single small 80-cm wide by 6-m long dike. This dike can be traced back into a larger body within the SIC and is the only example of this phenomenon found. A large multiply intruded body of BPS material dominates the exposures located in the vicinity of the old Aldermac Mine workings, and truncates another large body of BPS to the Northeast (Map 1.1). This body is interpreted to extend Northwest to the base of the Lucky Swine exposure (Map 1.1). Other examples of multiply intruded BPS exposures can be observed on outcrops 6/17-2, 6/21-2, 6/26-3, and 7/20-1 (see Map 1.1 for outcrop locations). An excellent example of an inhomogeneous exposure of BPS is located at outcrop 6/15-2.
Mineralogy

In thin section, an average mode consists of: albite-orthoclase perthite megacrysts, 60%; clinopyroxene, 20%; biotite, 15%; apatite, 3%; titanite, 2%; and trace opaque oxides (Table 3.3; Plate 3.2A and B). This facies can also contain minor amounts of interstitial anhedral feldspar. The perthite megacrysts are commonly reddish-brown, Carlsbad contact twinned, and heavily sericitised; and they can contain rare inclusions of titanite or biotite. In some exposures of BPS the feldspars weather out of the rock as complete euhedral crystals. Inspection of these reveals that most of these grains have the flattened Finisterre habit commonly associated with sanidine (Table 3.4). In thin section the feldspar grains are often characterised by patches of visible cross-hatched twinned orthoclase under a network of very irregular but crystallographically continuous, exsolved albite rods, veins and blebs (Plate 3.2C). Albite replacement is most extensive around the margins of these grains (Plate 3.2D), and appears to be a result replacement by Na from the surrounding matrix. While the above mode is considered to be representative of a typical example of a BPS rock, the modes can vary widely. Perthite megacrysts are typically present in modal amounts ranging from 30% to 75% (Table 3.3). Figure 3.2A is a histogram of estimated modal content of feldspar megacrysts from observed hand samples. The matrix of pyroxene and biotite can be aphanitic to phaneritic, but is generally the latter. Clinopyroxene is consistently greater in modal percent than biotite. The clinopyroxenes are 0.1-3 mm, typically 1 mm, in length. Grains can be anhedral to subhedral and are dominantly subhedral. The clinopyroxenes were identified based on their respective pleochroic colours, visible cleavage, and habit; and were backed up by electron microprobe data (Thompson, pers comm., 1997). Their composition ranges from aegirine to aegirine-augite (dominant), and compositionally zoned grains with aegirine cores surrounded by aegirine-augite rims (Plate 3.3A and B) are common. Biotite occurs as subhedral to euhedral grains approximately 1 mm in width. Under crossed polars they are pale to dark brown, or dark green in basal section. These basal sections often contain abundant fine rutile needles (Plate 3.3C). A common accessory mineral, titanite, can account for up to 5% of the total mode and occurs as euhedral grains (Plate 3.3D). Apatite grains are subhedral to euhedral and occur as individual grains (rare glomerocrysts) in the matrix. Qualitative electron microprobe analysis indicates that these
apatite grains are rich in fluorine. Recalculated matrix mineral modes indicate that bitotite can vary from 5% to 45% of the matrix mode, and clinopyroxene can vary from 40% to 95% of the matrix mode. Figure 3.3A shows a ternary plot of the recalculated matrix content of nine samples of BPS; note the variability in the modal volume content of the matrix mineralogy. Rocks of this facies usually exhibit sericitic alteration of feldspars. Local varieties have fine (less than 1 mm) acicular blue amphibole in fibrous radiating groups, often traceable as diffuse stringers or irregular patches (Plate 3.3B).

**Textures**

In rocks with lower feldspar modes, the megacrysts usually float in the mafic matrix, while rocks with higher feldspar modes often exhibit grain-to-grain contacts. An intergranular layer of mafic minerals often marks the contacts between feldspar megacrysts (Plate 3.4A). The contacts between megacrysts can also be devoid of any mafic material (Plate 3.4B). In both cases there appears to be a late stage (post transport) feldspar growth, yielding an overgrowth of feldspar around the mafics (termed here ‘poikilitic mantles’) and subsequent intermittent fusing of feldspars along their margins. Although rare, broken and refused feldspar grains have been observed. Bent feldspar grains are fairly common in some examples of this rock (Plate 3.4C and D), and are usually found in rocks with greater than 50% modal feldspar megacrysts. These grains appear to have behaved plastically, and no evidence of brittle failure is observed in the optical microscope.

**Varieties**

A common variety of this facies occurs in some outcrops of BPS as mafic dominated enclaves with diffuse margins. With the exception of the unusually low modal amounts of perthites these rocks are mineralogically and texturally identical to the normal BPS rocks. They can have fairly sharp or definite contacts with their BPS host, or more diffuse contacts where the modal megacrysts content drops off rapidly but continuously, moving into the enclave. On an outcrop scale these enclaves can be up to 1.5 m long. In thin section, a typical mode consists of: clinopyroxene, 50%; biotite, 42%; perthite megacrysts, 5%; apatite, 2%; and accessory opaques. See Figure 3.3A for a recalculated matrix mode plot of a mafic enclave. The perthite megacrysts appear to be identical to those in the regular BPS, and can be present as 5-15% of the total mode. Biotite grains are
anhedral to subhedral, typically 0.3 mm in diameter, ranging up to 3 mm. Clinopyroxenes grains are typically anhedral, less than 0.2 mm long with occasional euhedral phenocrysts up to 3 mm long. These are commonly aegirine-augite. Some of these phenocrysts are compositionally zoned.

An areally minor variety of the biotite-pyroxene facies is characterised by extensive alteration textures. Replacement textured calcite and muscovite give this rock an unusual mottled black and white matrix on both weathered and fresh surfaces. These rocks have a consistent modal perthite megacryst content averaging around 45%, and are only found in the vicinity of the old Aldermac Mine shaft and foundations (see Map 1.1). Calcite typically accounts for 10% of the total mode, and is found as anhedral grains isolated within perthite megacrysts, anhedral matrix grains, and as fracture fills. Associated muscovite occurs in the matrix (15% of total mode) as diffuse radial groups or clusters of anhedral to subhedral grains.

Two other minor varieties differ from the typical BPS facies in the shapes and sizes of their perthite megacrysts. The first contains feldspars with unusual aspect ratios; the feldspars are prismatic rather than tabular (Plate 3.5A). These feldspar grains appear to possess the elongated (prismatic) Baveno habit where a prism zone is formed parallel to the crystallographic x-axis by \{010\} and \{001\} (Deer et al., 1992). The second minor variety of BPS is characterised by an unusual, but consistent, bimodal distribution of feldspar megacryst sizes (Plate 3.5B).

**Fabrics**

These rocks typically contain well-defined SPO fabrics with varying mineralogical modes. In thin section, feldspar megacrysts are generally oriented in a subparallel arrangement (Plates 3.2A and 3.4A). A preferred orientation of prismatic pyroxene grains, yielding a lineation, can also be observed in the matrix (Plate 3.5C). In some finer grained examples of this facies, elongate biotite grains are found parallel to the dominant SPO defined by feldspar megacrysts and euhedral pyroxene grains (Plate 3.5D).

**Biotite Amphibole Syenite (BAS)**

On fresh surfaces this facies is characterised by closely packed pink to red feldspar megacrysts set in a fine-grained black matrix (Table 3.2). Weathered surfaces vary in
colour between a dull reddish black, to a bleached pink and black mottle. These rocks are texturally similar to rocks of the BPS facies.

**Occurrence**

Rocks of this facies occur as tabular bodies and plugs(?) in the western portions of the SIC (Maps 1.1 and 1.3). A small tabular body occurs as part of the Lucky Swine exposure, while two large outcrops of this facies are found near the northwest margins of the pluton. The geometry of these latter individual bodies is not clear. A 90% (modal) amphibole exposure occurs on the southeastern tip of one of these outcrops (Outcrop 6/25-8).

**Mineralogy**

A typical mode for this facies consists of: perthite megacrysts, 70%; alkali amphibole, 14%; biotite, 14%; and minor titanite and apatite (Table 3.3). The feldspar megacrysts are subhedral to euhedral laths ranging in length from 0.5-15 mm (Table 3.4). The grains are similar to the perthites as seen in the biotite pyroxene syenite (BPS), and they exhibit extensive clouding due to sericitic alteration. Carlsbad twins and discontinuous zoning are common. The alkali amphiboles are blue-black in hand sample, and in thin section they have a lavender-blue to yellow-brown pleochroism suggesting that they are an alkali amphibole (Deer *et al.*, 1992) (Plate 3.6A). Qualitative electron microprobe analysis using EDS indicates that these amphiboles are rich in Na, Ca and Mg. They are subhedral to euhedral, occurring as acicular masses or as individual laths, up to 7 mm long. These rocks appear to contain two stages of blue amphibole: a primary amphibole occurring as laths; and a secondary amphibole, occurring as acicular clots. Biotite grains are anhedral to euhedral, less than 1 mm long and commonly rutilated. Both apatite and titanite are euhedral, less than 1 mm long and occur in the matrix with biotite and amphibole. Late replacement calcite occurs in some large feldspar grains.

**Textures**

The feldspar megacrysts exhibit the same grain to grain contacts and overgrown margins as those found in the biotite pyroxene (BPS) facies rocks (Plate 3.6A).

**Fabrics**

These rocks possess identical fabrics to those found in the BPS. Feldspars are tightly packed with a strong SPO defined by the tabular faces of the megacrysts. Mafic minerals
and accessories are randomly oriented in interstitial clots. In some examples of this rock type the amphibole grains are preferentially oriented within the foliation planes defined by the feldspar megacrysts. The long axes of the amphibole grains define a lineation. This is seen in hand samples where a foliation plane is exposed, and in thin sections that are cut perpendicular to the foliation and amphibole lineation (Plate 3.6B).

**Pyroxene Amphibole Syenite (PAS)**

Rocks of this facies are typified by white to red feldspar megacrysts in a fine-grained mafic matrix (Table 3.2). On weathered surfaces the rocks have a characteristic bleached appearance, with pale pink to white megacrysts in a black matrix (Plate 3.6C). On fresh surfaces, the feldspars are reddish brown with a green-black matrix, giving the rock an overall red-brown appearance. The rocks generally exhibit a well-developed subparallel arrangement of megacrysts. Two major varieties of this facies can be distinguished based on grain size in the mafic matrix.

**Occurrence**

This voluminously significant facies occurs primarily in the southwestern portions of the SIC, but at least one exposure is seen in the central northern portion of the pluton (Maps 1.1 and 1.3). PAS facies rocks form a significant portion of the Lucky Swine exposure area, occurring in at least four separate (at the level exposed) bodies. One of these tabular bodies contains a sharp internal contact (Map 1.3) dividing rock types of the two sub-varieties listed above (i.e. amphibole grain size). This contact is parallel to contacts with other tabular bodies of different facies in the multiply sheeted Lucky Swine exposure.

**Mineralogy**

In thin section, a typical mode consists of: perthite megacrysts, 65%; alkali amphibole, 20%; aegirine-augite, 10%; quartz, 3%; minor apatite and titanite (Table 3.3). Figure 3.2B is a histogram of estimated modal content of feldspar megacrysts from observed hand samples. Biotite, if present, usually occurs in this facies in trace amounts. The perthite megacrysts are subhedral to euhedral, ranging in length from 2 mm to 45 mm (Table 3.4). Most megacrysts are zoned and exhibit extensive but patchy sericitization. Feldspars in this facies generally exhibit much more extensive albition than those grains found in the BPS and BAS, possibly contributing to the white colouration seen in
hand sample. Carlsbad twins, with slightly deformed twin planes are common. Aegirine-augite grains are commonly less than 1 mm long and subhedral to euhedral. Alkali amphibole grains are blue-black in hand sample and have a lavender to turquoise pleochroism in thin section. The size of the alkali amphibole grains provides the basis for the distinction between two major varieties of this facies. In one variety they occur as dominantly less than 0.5 mm long needles or laths, while in the second variety, the amphiboles are larger, occurring as 1-5 mm long columns (Plate 3.6D). There does not appear to be any continuum in amphibole grain size, between these two varieties. Quartz grains are anhedral and 3 mm or less in diameter. A plot of recalculated matrix mineral content (Figure 3.4A) suggests a wide variability in the proportions of the major matrix constituents.

One outcrop contains small amounts of a rock that appears to bridge the gap between rocks of this facies and the BPS facies. This rock is similar to the above rocks with the exception of an abundance of biotite in addition to medium-grained blue amphiboles and aegirine-augite (Plate 3.1C and D). Based on current map data this sub-variety is areally insignificant.

Textures

Feldspars are commonly in grain-to-grain contact and exhibit an overgrowth of matrix material at their margins. This margin material is free of sericitic alteration. The pyroxenes and alkali amphiboles appear to be intergrown, and occupy interstitial cavities, or lie in rows between adjacent feldspar megacrysts (Plate 3.8D). Small amounts of acicular amphibole appear to be a late alteration of the pyroxene. Anhedral quartz grains enclose interstitial matrix minerals and accessories.

Fabric

Feldspar megacrysts define SPOs that contain moderate to very well developed parallel arrangements of grains (Plate 3.8C and D).

Green Amphibole Syenite (GAS)

This facies type is characterised by abundant alkali feldspar megacrysts in a green aphanitic to phaneritic matrix of green amphibole laths and fine-grained matrix feldspar (Table 3.2; Plate 3.7A). In hand sample, the feldspars weather resistively, highlighting an
unusual abundance of holes or cavities in the megacrysts. The rock is also characterised on an outcrop scale, by the inclusion of abundant mafic and megacryst deficient pods of the same mineralogy as their host.

**Occurrence**

Rocks of this relatively minor facies are observed only in the southwestern portion of the SIC (Maps 1.1 and 1.3). These rocks appear to form a tabular body approximately 20 – 50 m wide and a minimum of 300 m long, which is part of the large multiple intrusion of different facies rocks which makes up the Lucky Swine exposure. The tabular body appears to curve dramatically from an approximately east-west trend to a northeast trend for its eastern portion. (There are no metamorphic deformation features in the GAS rocks).

**Mineralogy**

In thin section a typical mode consists of: orthoclase megacrysts, 43%; fine-grained K-feldspar, 35%; amphibole, 20%; and clinopyroxene, 2% (Table 3.3). Orthoclase megacrysts are subhedral to euhedral (sometimes fragmented), with sharp margins, pink, and spectacularly zoned (Plate 3.7B). They range in length from 1-12 mm (Table 3.4), and are considerably more compact and equant than the perthite laths found in the biotite-pyribole facies rocks. Many of the grains appear to possess the Carlsbad habit commonly associated with primary igneous alkali feldspars. Trains of anhedral, 0.1-mm scale, microlites parallel to crystal faces define the rhythmic discontinuous zoning. Preliminary electron microprobe analysis indicates that these microlites are K, Na-feldspar (Plate 3.7C and D). The matrix is aphanitic to phaneritic, consisting of polygranular 0.01-0.05 mm anhedral grains of feldspar, and 0.01-0.1 mm laths of a green amphibole (probably hornblende). Electron microprobe analysis of the matrix feldspars in the bulk of the rock reveals an albitic composition. Rare relict grains (less than 2 mm long) of pyroxene are distributed throughout the matrix as well as trace amounts of apatite. These grains possess the external morphology of pyroxene and appear to contain alteration phases and some vestiges of green clinopyroxene. Preliminary electron microprobe analysis of the relict grains reveals a material with a composition rich in Al, Si, Ca, Fe and REEs, as well as late quartz, and a late iron oxide.
Textures
In thin section some megacrysts possess perthitic cores, and others have textures giving the appearance of fragmented or replaced yet crystallographically continuous grains (Plate 3.8A). While the megacrysts generally possess very sharp margins and exhibit no evidence of the overgrowth seen in the BPS facies, many grains possess dramatic embayments (Plate 3.7C) which cut across the microcline-defined zoning (in hand sample, these give the larger grains a ‘swiss-cheese’ appearance) (Plate 3.7A). The embayments are filled with matrix material, including rare relict pyroxenes; yet in some of the cavities the mean grain size of this infill is greater than that of the surrounding matrix (Plate 3.7D). Electron microprobe analysis of the matrix found within megacryst cavities reveals that the matrix feldspar is orthoclase, while the amphiboles are inhomogeneous and consist of two Ca, Na rich phases (hornblende?).

Varieties
A significant variety of this facies occurs as mafic enclaves in the more voluminously significant GAS host. These enclaves possess the same mineralogies and textures as their host, and differ only in their modes and occurrence (Plate 3.8B). A typical mode consists of: orthoclase megacrysts, 15%; polygranular alkali feldspar, 40%; green amphibole, 40%; relict clinopyroxene, 2%; unidentified polygranular pockets, 2%; and trace amounts of apatite.

Fabric
In thin section the feldspar megacrysts can exhibit a weak SPO. The amphibole rich matrix of the mafic enclaves exhibits a strong SPO (lineation), which bends or kinks around the ends of the microcline phenocrysts (Plate 3.8C). The enclaves are typically elongate and appear to have behaved plastically in contact with the host green porphyry (Plate 3.8D).

Quartz Phyrice Syenite (QPS)
This facies type is pale pinkish white in hand sample on both weathered and fresh surfaces. It is characterised by alkali feldspar and quartz megacrysts in a white aphanitic matrix of polygranular feldspar and anhedral quartz, with mafics (Table 3.2).
Occurrence
Rocks of this facies occur in a single large tabular body within the Lucky Swine exposure (Maps 1.1 and 1.3). The body is approximately 60m wide and a minimum of 250 m long, and is in contact with the texturally similar GAS facies (Plate 3.1B).

Mineralogy
In thin section a typical mode consists of: orthoclase, 45%; fine-grained alkali feldspar, 23%; opaques, 10%; anhedral quartz (?), 10%; alkali amphibole, 7%; and quartz megacrysts, 5% (Table 3.3; Plate 3.9A). Feldspar megacrysts are tabular and typically 1-15 mm long (Table 3.4).

Textures
The orthoclase megacrysts exhibit the same textures as those found in the GAS. These textures include fragmented remains of feldspar grains with preserved euhedral faces, and/or extensive embayments (Plate 3.9A). Most quartz grains also exhibit this spectacular embayment, leaving only skeletal grains in some instances (Plate 3.9B and C). In thin section, the quartz grains exhibit well-defined rhythmic concentric zoning, defined by trains of anhedral crystallites (Plate 3.9C).

Fabric
No SPOs of mineral grains are detectable in hand sample or thin section.

Amphibole-Quartz Syenite (AQS)
Rocks of this facies are bleached white to dirty grey on weathered surfaces and salmon pink to red on fresh surfaces. They contain abundant euhedral feldspar megacrysts, tightly packed together, in an aphanitic felsic matrix, with rare mafic grains (Table 3.2). There is a strong parallel arrangement (SPO) of feldspar megacrysts in this facies.

Occurrence
Rocks of this facies type occur predominantly in the Lucky Swine outcrop area (Map 1.3). They occur as at least one large plug and as smaller tabular bodies crosscutting other, more mafic facies. Rocks of this facies are also found in significantly smaller and higher aspect ratio dikes in other portions of the pluton (as well as the surrounding volcanic rocks) and will be discussed in the following section.
Mineralogy

A representative mode for this facies consists of: perthite megacrysts, 70%; quartz, 15%; fine-grained alkali feldspar, 10%; mafics (amphiboles) and opaques, 5% (Table 3.3; Plate 3.10A). Varieties with only trace amounts of mafics or opaques are common. The feldspar megacrysts are subhedral to euhedral, 1-10 mm long (Table 3.4), zoned, and Carlsbad twinned. Most of the feldspar grains have symmetrically curved crystal faces and an unusual extinction figure under crossed polars, which manifests itself as a sweeping extinction as the stage is rotated (Plate 3.10B, C and D). Many of the grains appear more equant than those tabular grains found in the BPS and BAS facies. Anhedral grains of unaltered plagioclase occur interstitially. The remainder of the interstitial matrix is composed of: very fine-grained anhedral feldspar; less than 0.1 mm grains of orthoclase; fine-grained anhedral quartz; and 0.3-6 mm long mafic laths. These mafic laths are commonly black amphiboles, but in many samples these appear to have been altered and replaced (pseudomorphed) by zoned sulphides, unidentified opaque phases and granoblastic feldspar cores. The spread of data points on a plot of recalculated matrix mineral content (Figure 3.4B) suggests a wide variability in the proportions of the major matrix constituents.

Textures

Point contacts between perthite megacrysts are common. Many of these point contacts are characterised by minor indentations into crystal faces and localised accumulations of granoblastic feldspar. Interstitial quartz shows some evidence of deformation i.e. undulose extinction in crossed polars.

Fabric

Feldspar megacryst SPOs in this facies are typically well defined (Plate 3.10A). Megacrysts can be in grain-to-grain contact or freely floating in matrix.

Syenite/Trachyte Porphyry Dikes

Syenite and trachyte porphyry dikes occur both in the SIC and in the surrounding volcanic rocks. Similar to the rocks forming the bulk of the SIC, the dikes have varying mineralogical contents, modal compositions, and colour indexes. Variable texture and granularity complement this range in composition, with feldspar megacrysts ranging in
size from very fine-grained to very coarse-grained. The rocks classified here as dikes differ from the rocks that comprise the bulk of the SIC based on the following criteria:

1) They are dominantly felsic in appearance.
2) They are generally aphanitic feldspar porphyries while most SIC rocks are feldspar megacrystic phanerites.
3) They occur as individual intrusions (as opposed to part of a parallel multiply sheeted intrusion).
4) They cut the bedding or confining contacts of their host rocks at a high angle.
5) They have significantly higher (traceable) aspect ratios than those single bodies (or multiple intrusions) which make up the SIC.

Whole rock and trace element geochemical analysis (Thompson, 1997) indicates that these rocks are not petrologically associated with the host volcanic rocks, but are closely related to the rocks comprising the bulk of the SIC.

Facies Classification Scheme
Most of the dikes contain alkali feldspar megacrysts whose size, form, and modal volume proportion can vary widely, not only between different rock types, but also within an individual dike. Different matrix compositions, modal contents and mineralogical textures complement this variability in feldspar characteristics. Just as the rocks forming the larger bodies within the SIC can be categorised into facies, so can those rocks which form the dikes. They are grouped here into five broad facies, based on matrix composition, modal contents and mineralogical textures. Table 3.5 lists each facies (its name based on characteristic matrix mineralogical content), the facies abbreviation, and the IUGS recommended name for a rock sample that is representative of that facies. Three of these dike facies contain similar mineralogical content to facies found in the SIC (with different textures, distributions, and granularity). As a result of these similarities some of these dike facies are potential aphanitic analogues (porphyritic trachytes) of some of the dominantly phaneritic SIC rocks (syenites). These proposed equivalents are also included in Table 3.5, and discussed below where appropriate.
Chapter III

**Facies Variation and Timing Relationships**

Similar to those relationships found between the dominant facies comprising the SIC, there appears to be a temporal and compositional gradation of dike compositions, from early mafic rich facies, through to later felsic rich rock types. As the crosscutting relationships between the five dike facies are clearer than for the SIC facies, they are presented here in descending order from oldest to youngest (note that this order corresponds with a change from mafic rich through felsic rich modal compositions).

**General Map Pattern of Dikes**

The majority of the volcanic hosted dikes are concentrated around the eastern, south-eastern, southern, and south-western margins of the complex (Map 1.1), and numerous dikes to the north-west have been reported (Gunning, 1927). They are often found in the vicinity of, or in contact with the SIC. Most of the dikes contained within the SIC are concentrated in its compositionally variable western portion. At the Mill Hill locality (Maps 1.1 and 1.2), individual dikes are observed crosscutting both SIC material and volcanics. Dikes found intruded into the volcanics and the SIC are generally characterised by sharp margins, and range in width from a few centimetres to 3 metres. They can be traced on individual outcrops for up to 150 m, but correlation between adjacent outcrops is difficult.

**Dike facies:**

*Biotsite Pyroxene Dikes (BPD)*

Rocks of this facies are characterised in hand sample by an overall purple colour on fresh surfaces, and a mottled pink and purple colouring on weathered surfaces. They contain abundant feldspar and clinopyroxene phenocrysts in a purple aphanitic matrix (Table 3.5). The feldspar megacrysts define a range of weak to strong shape preferred orientations. These dikes appear to be the compositional equivalents of the biotite-pyroxene syenite (BPS) (Table 3.5). The main differences between these dike rocks and their proposed SIC equivalent lies in variations in modal amounts of feldspar megacrysts and matrix minerals, and differences in matrix granularity and texture.
Occurrence

The earliest dikes intruded are those of the biotite pyroxene dikes (BPD) and biotite amphibole dikes (BAD) facies (treated below). Dikes of the BPD facies are generally found only in the volcanics surrounding the SIC, with the exceptions of the Mill Hill locality, where some can be found cutting both volcanics and SIC material (Map 1.2), and one unusual megacryst deficient dike in the Lucky Swine exposure (Map 1.1). The majority of the BPD facies dikes detected are located around the southern and eastern margins of the SIC. Although it is difficult to trace or correlate dikes between outcrops in the Aldermac area, some of the larger outcrops provide the opportunity to investigate the structural and petrographic attributes of a dike over a reasonable strike length. On the Mill Hill outcrop (Maps 1.1 and 1.2), there are several BPD dikes that become narrower with increasing distance from the volcanics. Two of these dikes are approximately 40 cm wide near the SIC-volcanic contact, and moving away from the SIC (South) over a distance of 135 m, they narrow to 2 cm in width (Map 1.2). This narrowing is also coincident with a decrease in their modal feldspar megacryst content and grain size. In one dike, feldspar megacrysts average 8 mm in length and account for 25% of the mode near the SIC volcanic contact, while the mode decreases to 10%, 3 mm long feldspars at approximately 100 m distance from the SIC.

Mineralogy

In thin section, a representative rock in this facies exhibits the mode: fine grained feldspar matrix grains, 30%; perthite phenocrysts, 30%; augite, 25%; biotite, 10%; opaques, 5%; and trace apatite (Table 3.6; Plate 3.11A). Figure 3.2C is a histogram of estimated modal content of feldspar megacrysts from observed hand samples; note the difference between this and Figure 3.2A, the histogram for the BPS facies. Two varieties of feldspar phenocrysts occur in these dikes: (1) large, 1-40 mm long, salmon pink perthites, and (2) small, 2-10 mm long, Carlsbad twinned purple perthites (Table 3.4). These two types of phenocrysts can occur separately or together, yielding three distinctive subcategories of this facies. The salmon pink perthites appear to have a more systematic growth of albite veins than the unusual perthites common in the BPS and BAS facies. Smaller, subhedral feldspar laths, typically 0.2 mm long, in irregular radiating clusters or random orientations make up the felsic portion of the matrix. Some of these matrix feldspar grains
are unaltered plagioclase. Pyroxene appears in this facies as euhedral 1-2 mm long aegirine megacrysts, and as subhedral 0.1-0.3 mm groundmass grains. Biotite grains are pale-brown in plane light, anhedral to subhedral and 0.25-1.5 mm wide. Figure 3.3B shows a ternary plot of the recalculated matrix content of six samples of BPD. The variability in matrix composition is similar to that seen for BPS samples (Figure 3.3A), but with systematically higher matrix feldspar content.

Textures
Both varieties of feldspar phenocrysts are euhedral with very sharp margins, and unaltered rims (Plate 3.11B). The smaller euhedral laths appear to be unaltered while the larger perthites exhibit patchy sericitic alteration (Plate 3.11B). Larger pyroxene megacrysts occasionally exhibit simple twins, and many appear damaged; some exhibiting replacement with calcite, while others are fringed with, and/or contain anhedral opaques and an unidentified phase.

Varieties
In some rocks a lack of biotite in the mode appears to be compensated by replacement textured chlorite, including rutilitated grains. This chlorite is also seen in fractures in larger pyroxene grains. As a result of this chloritization, dikes of this facies are a characteristic green colour in hand sample, consisting of reddish purple feldspar megacrysts in an aphanitic to phaneritic green matrix.

Fabrics
Most dikes composed of this facies contain well-formed SPOs defined by feldspars floating in matrix (Plates 3.11A and B).

Biotite Amphibole Dikes (BAD)
On fresh surfaces, rocks of this facies are characterised by oxblood to purple tabular feldspars in a fine-grained blue matrix, and mineralogically these dikes appear to be the compositional equivalents of the biotite amphibole syenite (BAS) facies rocks (Table 3.5). The main differences between these dike rocks and their proposed SIC equivalent lies in variations in modal amounts of feldspar megacrysts and matrix minerals, and differences in matrix granularity and texture.
Occurrences

These dikes are only found intruded into the volcanic rocks around the southern margins of the pluton (Map 1.1).

Mineralogy

In thin section, a typical mode consists of: perthite phenocrysts, 35%; feldspar matrix grains, 30%; amphibole, 15%; biotite, 10%; opaques, 5%; calcite, 3%; quartz, 1%; and trace apatite (Table 3.6). The perthite megacrysts are blood red to purple in colour, 2-15 mm long, subhedral to euhedral laths (Table 3.4). Carlsbad twins and discontinuous zoning are common. Amphibole grains are subhedral to euhedral laths, 0.1-2 mm long, exhibiting a pale brown to blue-violet pleochroism. Qualitative electron microprobe (EDS) analysis indicates that these amphiboles are Ca and Mg rich. Biotite grains are anhedral, 0.2-1 mm wide, and exhibit pale-dark brown pleochroism (rather than the green to brown pleochroism seen in the BPS). The remainder of the matrix consists of subhedral feldspar laths (including plagioclase), in an interlocking arrangement. These are typically 0.2-0.5 mm long. Minor anhedral quartz, less than 0.3 mm, occurs as interstitial matrix material.

Textures

Perthite phenocrysts have patchy sericitic alteration, with the exception of clear albitic rims. Some examples of this facies contain feldspar megacrysts with rounded (resorbed or abraded?) corners (Plate 4.7A). Replacement textured calcite occurs as anhedral grains in feldspar megacrysts, and in the matrix.

Fabrics

Samples of this facies usually have a strong shape preferred orientation of feldspar megacrysts floating in matrix.

Amphibole Quartz Dikes (AQD)

This characteristically pink rock type is ubiquitous throughout the SIC and the host volcanic rocks. Dikes containing rocks of this facies are essentially identical in composition and texture to the larger and more complex bodies found in the SIC (Tables 3.4, 3.5 and 3.6), with the exception of slightly lower modal feldspar megacryst content.
Figure 3.2D is a histogram of estimated modal content of feldspar megacrysts from observed hand samples.

**Occurrence**
Dikes of this facies type are found around the eastern, southern, and western margins of the SIC, as well as inside the pluton in its compositionally varied western portion (Map 1.1).

**Fabric**
Feldspar SPOs in this facies are generally well defined (Plate 3.10A). Feldspars can be in grain to grain contact or matrix supported.

**Quartz Feldspar Porphyry Dikes (QFD)**
This distinctive facies is typified by a salmon red weathered surface and a pink fresh surface showing euhedral quartz and feldspar grains in a pink matrix (Table 3.5).

**Occurrences**
This facies is seen intruding into both the SIC and the surrounding volcanic rocks. These dikes are common around the southern and western margins of the SIC and inside its western regions (Map 1.1).

**Mineralogy**
Representative rocks in this facies exhibit the following mode: feldspar phenocrysts, 75%; fine-grained matrix feldspar, 10%; quartz, 10%; pyroxene, 3%; opaques, 1%; trace calcite, and amphibole (Table 3.6). Feldspar phenocrysts are varied including perthites, orthoclase and albite-twinneed plagioclase feldspars. No evidence of embayment of the feldspar grains was detected. Grains range in size from 0.3-5 mm long (Table 3.4). The generally smaller plagioclase grains are unaltered and subhedral. The 1-5 mm quartz grains are subhedral to euhedral, undeformed, and contain an outer zone or rim of very fine-grained anhedral inclusions (Plate 3.11C). Minor submillimetre, subhedral pyroxene grains occur in the matrix. Trace amounts of calcite and a fibrous blue amphibole appear as alteration phases.

**Textures**
Many of the feldspars possess a variety of textures including patchiness, overgrowths, monzonitic texture, and inclusion trains (Plate 3.11D). Larger grains tend to be euhedral
while smaller grains are intergrown and subhedral. This gradation continues down to 0.1 mm, anhedral, polygranular matrix feldspar, filling in interstitial voids.

**Fabric**

A strong SPO lineation is defined by the long axes of doubly terminated quartz grains in some examples of this facies.

**Quartz Amphibole Dikes (QAD)**

This unusual facies is characterised in hand sample by a distinctive mottled light green and pink weathered surface, and a dark green fresh surface. Euhedral quartz grains and pink euhedral feldspars are visible in a cryptocrystalline pale green matrix (Table 3.5).

**Occurrence**

These dikes are only found in the western portion of the SIC (Plate 3.13B; Map 1.1).

**Mineralogy**

A representative mode for this rock type consists of: euhedral quartz, 40%; alkali feldspar megacrysts, 20%; fine-grained matrix feldspar, 20%; amphibole, 15%; and anhedral quartz, 5% (Table 3.6; Plate 3.12A). Feldspar and quartz grains are subhedral to euhedral and 1-15 mm long and 0.2-3 mm wide, respectively (Table 3.4). Amphibole grains are pale green in thin section (PPL) and are typically less than 0.2 mm long.

**Textures**

Feldspars in this facies commonly exhibit perthitic textures occasionally masked by patchy sericitic alteration, while some grains appear to preserve unaltered orthoclase textures. Some of the feldspars are fragments of euhedral grains but there are no embayments as seen in the GAS and QPS facies of the SIC. Glomerocrysts of small matrix feldspars are also common. Quartz phenocrysts are subhedral to euhedral and can also be found in glomerocrysts (Plate 3.12B). All quartz phenocrysts contain abundant inclusions of very fine amphibole needles. These needles are randomly oriented in misshapen or anhedral grains, while they are aligned parallel to crystal faces in subhedral and euhedral quartz grains (Plate 3.12C). This alignment of inclusions defines concentric zoning in the quartz grains where the inclusions are typically concentrated near the outer margins of the quartz grains. Rare feldspar grains contain similar needles that are randomly oriented.
Fabric

These dikes exhibit an unusual fabric wherein larger feldspar megacrysts line the margins of the dike (Plate 3.12A).

Dike Orientations

Measured dike orientations for each facies group are found to form consistent sets, which may be single or multiple (Figure 3.5). Collectively, most dikes possess trends that fall in a tight range from NNW to NNE (Figure 3.6). Where measurable, the dips of most dikes are vertical or near vertical.

While a cursory study of the map suggests that orientations of dikes are simply related to a radial map pattern of dikes (sharing a centre somewhere in the SIC), in some localities, including individual outcrops, dikes with wide variations in orientation can be observed. The numerically and voluminously significant biotite pyroxene dikes (BPD) occur in three main orientation sets, with peak values of 015°, 140° and 165°; on the Mill Hill outcrop (Map 1.2), dikes from all three of these orientation sets can be observed (Figure 3.5).

Crosscutting relationships, detectable on single outcrops as well as at map scale, reveal a temporal change in dike orientations, which is coincident with the temporal change in dike compositions (facies). This change can be seen between different dike facies and within individual dike facies. At the mill Hill location (Maps 1.1 and 1.2), the earliest BAD and BPD dikes possess a peak trend around 015°. These are cut by a BPD set with peak orientations of 165°, which are in turn cut by another BPD set with a peak orientation of 140°; yielding an overall counter-clockwise rotation in dike orientation of 55° (Maps 1.1 and 1.2). Dikes that match these facies types and trend sets are also abundant in other parts of the map area. Dikes of the AQD facies possess orientations with a peak value around 002°, while QFD facies dikes have peak orientations around 165°. Dikes of the QAD facies show a return to northeasterly peak orientation values around 045°.
Other Petrologic and Structural Features of the Area

Veins
Post-dating the intrusion of the SIC and syenite dikes, massive milky quartz veins ranging from 0.5 cm to 10 cm wide are found within the SIC and surrounding volcanics. They are observed truncating the quartz amphibole dikes (QAD)(Plate 3.13C). Quartz veins located throughout the SIC and volcanic pile exhibit three bimodal peak orientations of 010°, 075°, and 140°, the strongest of which lies at 014° (Figure 3.6). These are in turn crosscut by diffuse stringer veins of fibrous blue amphibole (Plate 3.13D) whose peak orientation trends 015° (Figure 3.6). Veins of both types are more common in the western and northern portions of the SIC. They are rare in the BPS dominated southeastern portions of the SIC.

Faults and Joints
The structural complexity of the Aldermac Mine area becomes apparent upon attempts to map the volcanic stratigraphy. Local oppositions in younging directions and truncation of contact horizons make structural and lithological interpretations difficult. Initial interpretations by Ambrose and Ferguson (1945) inferred large folds to explain these difficulties, but structural and stratigraphic data from recent drilling and mapping programs suggests the presence of numerous fault blocks, some with opposing rotations, but all with stratigraphy dipping between 30° and vertical.

While most of these faults can only be delineated from drill core data, some can be reasonably inferred from strong airphoto lineaments or pronounced topographic lows. Only one fault, the Mackay Lake Fault, was reliably detected in the field by the author (Map 1.1). This fault strikes 075° and exhibits visible shear phenomena in outcrop exposures of volcanic rocks. The dikes in this locality appear to have been cut by a minor reactivation of this fault, yielding a consistently observed dextral offset of 10-20cm.

Regular and irregularly spaced joints are common in many of the volcanic exposures. These joints commonly occur as conjugate sets and rarely cut the syenitic dikes (Plate 4.8D). The orientations of the major and minor joint sets are 008° and 062° respectively (Figure 3.6). (Note the coincidence of the orientations of the joints, veins, and dikes at approximately NNE.)
DISCUSSION

The elongate, roughly north-south trending SIC has a heterogeneous interior dominated by multiple intrusions of mafic rich syenite and other less voluminous facies. The distinctive variations in mineralogical content and textures yields a set of six distinct syenite facies based on these characteristics. Fine and medium grained varieties of the mafic rich BPS facies are found in contact with the volcanic pile in several locations; often exhibiting evidence of intrusion into hot volcanics, leaving rounded rafts of volcanics in syenite. These features suggest that portions of the SIC were intruded while the volcanic pile was quite hot. This could be due to re-heating of the volcanics by the SIC (although there is only low-grade metamorphism in the volcanics) or a close temporal relationship between formation of the volcanic pile and intrusion of portions of the SIC i.e. synvolcanic intrusion. (Syenite that is mineralogically and texturally identical to that found in the SIC was found injected into the volcanic pile as a single small 6 m long dike. This dike can be traced back into a larger body within the SIC and is the only example of this phenomenon found). Early intrusions of syenite within the SIC exhibit conformable contacts with each other. This can yield sheeted dikes of material of the same facies, varying only in granularity and/or modal amounts of megacrysts, or multiply intruded, sheeted parallel bodies of different facies. Large sheeted dike units are interpreted to discordantly cut other large units. This phenomenon becomes more common with later felsic rich intrusions.

Abundant syenitic/trachytic dikes have been reported intruding into the volcanics to the Northwest of the SIC, and are observed radiating around its eastern, southern and western borders, as well as within in its heterogeneous western portion. Some of these dikes are compositionally similar to facies that make up the bulk of the SIC, but they differ in texture and mode as well as intrusion morphology. The main differences between dikes and the larger SIC bodies are granularity, aspect ratio, and contact nature. Dikes tend to have lower modal amounts of feldspar phenocrysts and aphanitic groundmass minerals as well as considerably higher traceable aspect ration than their larger SIC counterparts. As a result of these observations, the syenite/trachyte dikes are divided into five distinctive facies based on mineralogical mode (of the matrix) and associated mineralogical textures. Spatially repeated crosscutting relationships indicate a
temporal relationship between dike facies, ranging from older mafic rich varieties (BPD and BAD) to the youngest quartz rich QADs.

The syenite/trachyte dikes found in the volcanics surrounding the SIC cannot be physically traced back into the complex, nor can the dikes found within the SIC be traced out into the volcanics. Although some of the earliest BPS facies dikes exhibit slightly irregular contacts with the volcanics, the majority of the dikes intruded into the volcanics have sharp margins (unlike the SIC-volcanic contacts). Thus the majority of dikes appear to have been intruded into a cooler volcanic host (i.e. apahanitic groundmass, sharp contacts).

The temporal change in facies composition is accompanied by a change in dike orientation. Although a dike’s location around the margins of the SIC bears an important relationship to its orientation, there is a temporal control on dike orientations exhibited around the southern margins of the SIC. Here, dikes of the numerically dominant facies type (BPS) are intruded in groups bearing three consistent orientations, the changes between sets rotating counter-clockwise from NNE to NNW, sweeping a total of 55°. This phenomenon can be seen around the southern regions of the SIC as well as on individual outcrops. Later facies match the NNW orientation, with an apparent reset back to NNE and NE orientations, in the final recorded dike facies. Later stage hydrothermal stringer veins also possess a peak orientation around NNE. The dominantly north south trending orientations of many of the structural features in the Aldermac mine area suggests a strong regional structural control on the intrusion geometry of the SIC and related dikes. (Although this does not account for the dominantly east-west extension of many of the larger bodies that make up the interior of the SIC).

Megacryst Crystallisation History
The mineralogies of all of the rocks found in the SIC and its related dikes exhibit primary igneous textures, with the exception of minor amounts of metasomatic replacement phases in some facies. These metasomatic phases include the diffuse stringer veins of fine acicular amphibole, and replacement calcite in the ‘mottled’ variety of BPS. The majority of facies found in the SIC and related dikes contain feldspar megacrysts with one or more of the following characteristics:
1. Carlsbad twins.
2. Discontinuous chemical zoning.
3. Numerous small inclusions, often in trains defining zonation.

These characteristics record an earlier crystallisation history of the feldspars that occurred prior to transport to their current locale, thus suggesting an origin in a subjacent magma-chamber, rather than a complete in situ nucleation and crystallisation. The presence of mafic grains as inclusions in the interior of feldspar grains, mafic grains that are petrographically similar to those found in the matrix, suggests that at least some of the mafics also may have grown in the source magma chamber. In most facies, late stage, syn-emplacement and post-emplacement crystallisation appears to be limited to matrix material such as mafics and quartz/feldspar microlites and crystallites. In the BPS, mantling of feldspars, yielding sub-poikilitic envelopment of mafic minerals in the outer margins of feldspar megacrysts (heteradcumulate texture, Shelley, 1993, p.216) is indicative of late stage (post-transport) crystallisation of liquid residuum.

Modal Variability and Source Magma Chamber Fractionation

While the rocks of the SIC and its related dikes can be categorised into eleven igneous facies based on their mineralogical compositions and related textures, there still exists a wide variation in the modal amounts of the characteristic minerals present within each facies. This variation is highlighted in the wide range of modal (volume) content of feldspar megacrysts within individual facies (see Figure 3.2 for histograms of megacryst content of samples of four selected facies). Recalculation of matrix mineral contents indicates a further variability in the relative proportions of the dominant matrix minerals in each of the respective facies (Figures 3.3 and 3.4). In addition to map scale variations in facies, this modal variability can be present in individual rocks at outcrop, hand, and thin section scale. This striking variability in the relative proportions of all of the minerals present in the SIC rocks indicates a fractionation of the magma which formed those rocks at multiple stages during their development, i.e. fractionation of liquid from crystals.
Feldspar Modes and *In situ* Fractionation

Although syenitic rocks are generally thought to be derivative rather than parental magmas, the high modal percentages of feldspars megacrysts found in some facies within the SIC (Plate 3.2A and Plate 3.8A) present a magma transport problem. Marsh (1981) found that the limiting solid content for flow in basaltic lava is 55-60%. Following the assumption that all of the feldspar megacrysts were present at the time of transport, and given the possibility that many of these magmas also contained previously crystallised mafic minerals, it is difficult to rationalise the transport (over long distances) of a magma with 75% feldspar megacrysts or higher. Note however that some authors report flow of slurries with crystal content near 90% (A.R. Cruden, *Pers. Comm.*, 1998). Furthermore, in most high feldspar content facies, there is a lack of cataclasis associated with extensive grain to grain collisions, which would occur during transport flow of magma of this type. It is possible that the larger mafic rich enclaves found in the BPS could represent residual magma that has been squeezed out by filter pressing. The diffuse nature of their margins, and minor megacryst content of some of the enclaves support this proposal. In thin section, some evidence of late, semi-solid state shearing of groundmass, which might accompany some form of filter pressing (Smith *et al.*, 1993) was detected.

Many of the exposures of the SIC and the syenitic dikes exhibit fabrics defined by shape preferred orientations, in the form of lineations, foliations or a combination of both. These are visible in hand sample and thin section. While a lack of extensive metamorphic (recrystallisation and/or penetrative plastic deformation) textures implies that these fabrics are related to igneous transport processes, what stage or stages of transport are preserved, is open to debate. It is likely that some of these fabrics preserve both:

1. The initial transport of megacrysts.
2. The expulsion of matrix after cessation of transport of the megacrysts (i.e. during filter pressing).

Evidence for this will be discussed further in Chapter IV.

The unusual textures found in the GAS and QPS, such as embayment and/or fragmentation of feldspar megacrysts (Plate 3.7A and C), suggest slightly different emplacement mechanisms for these rocks. Both contain feldspars with chemical and inclusion defined zoning, but many of these grains are fragmented and heavily corroded.
The zoning is indicative of growth in a magma chamber, while the corrosion implies a remelting of the magma at some later stage of the megacrysts history. The presence of abundant matrix feldspar indicates that the magma was saturated in feldspar thus reheating or rehydrating of the magma are likely mechanisms causing this remelting. Finally the cataclastic texture of the feldspar megacrysts suggests high-stress grain-to-grain interactions during transport. Note that these rocks (GAS and QPS) generally contain significantly lower feldspar megacryst modes than the rocks of the BPS, which do not exhibit cataclastic textures.

**SUMMARY**

The lithology of the Aldermac mine area can be broken down into three main groups of rock types based on composition and mode of occurrence:

1. The Syenite Igneous Complex (SIC).
2. The syenite dikes found within and outside the SIC.
3. The volcanic pile which hosts the SIC and dikes.

The volcanic rocks range from mafic to intermediate in composition. They are heavily silicified, and have undergone subgreenschist metamorphism, with little or no evidence of regional penetrative deformation.

The SIC is subdivided into six main facies groups based on spatially repeated modal mineralogies and associated textures. The rocks in these groups typically fall in the IUGS classification as alkali feldspar syenites and alkali feldspar quartz syenites.

The syenite dikes found surrounding and within the SIC are subdivided into five main facies groups following the model for the SIC. Some of these facies appear to be aphanitic mineralogical equivalents to the facies found in the SIC. The rocks in these groups typically fall in the IUGS classification as alkali feldspar syenites/trachytes, alkali feldspar quartz syenites/trachytes, and alkali feldspar granites/rhyolites.

Facies of both the SIC and related dikes exhibit primary mineralogies of igneous origin with megacrysts of magma chamber origin. Late stage, post transport mineralisation is limited to final crystallisation of interstitial material and mantling of feldspars. Minor metasomatic mineralisation is encountered. Shape preferred orientations of feldspar megacrysts dominate most of these rocks. Very high modal feldspar contents
(50-80%) are observed in many of the rocks in the SIC. The succession of mineralogies in the different facies suggests an evolution (fractionation) of the magma(s) that formed those rocks, within an underlying magma chamber or chambers. Some of the facies exhibit extensive redissolution of their feldspar megacrysts in an already feldspar rich matrix, indicating a late addition of heat and/or water. The wide variability in modal mineral composition and proportions indicates extensive fractionation of magmas within each facies that must have occurred in the underlying magma chamber(s) as well as at the level of exposure (i.e. filter pressing).
Figure 3.1. Diagrammatic representation of idealised lineations (L) and foliations (F), defined by the preferred orientation of idealised elements, which are in this study individual mineral grains. (a) Simple linear fabric defined by the shape preferred orientation of elongate linear grains. (b) A combination of a foliation defined by the shape preferred orientations of tabular grains, and a lineation within the foliation plane, defined by the long axes of the triaxial tabular grains. (c) A linear fabric defined by a common axis of intersection of variably oriented tabular grains.
Figure 3.2. Histograms of modal content of feldspar megacrysts estimated from hand samples.
(A) BPS facies rocks, n=75.
(B) PAS facies rocks, n=23.
(C) BPD facies rocks, n=63.
(D) AQD facies rocks, n=19.
Figure 3.3. Ternary plots of the recalculated matrix content of: (A) BPS facies rocks; and (B) BPD facies rocks. Note the variability in the modal volume content of the matrix mineralogy. Feldspar denotes anhedral, interstitial matrix feldspar. All values are modal estimates from thin section analysis. The triangular symbol represents a calculated average for the data points shown. The numerical label beside each symbol indicates the modal feldspar content of the whole rock mode (before recalculation of matrix content).
Figure 3.4. Ternary plots of the recalculated matrix content of: (A) PAS facies rocks; and (B) AQD facies rocks. Note the variability in the modal volume content of the matrix mineralogy. All values are modal estimates from thin section analysis. The triangular symbol represents a calculated average for the data points shown. The numerical label beside each symbol indicates the modal feldspar content of the whole rock mode (before recalculation of matrix content).
Figure 3.5. Frequency rose diagrams for the orientation of dikes found within the SIC and the surrounding volcanic rocks. All values are unweighted.
Figure 3.5

(A) Biotite-Amphibole Dikes (BAD)

(B) Biotite-Pyroxene Dikes (BPD)

(C) Amphibole-Quartz Dikes (AQD)

(D) Quartz-Feldspar Dikes (QFD)

(E) Quartz-Amphibole Dikes (QAD)

(F) All Dikes
Figure 3.6. Frequency rose diagrams for the orientation of all of the structural features measured in the SIC and the surrounding volcanic rocks.

(A) Orientations of all of the dikes found in the SIC and the surrounding volcanic rocks.

(B) Orientations of all feldspar foliation fabrics found in the SIC. Each data point typically represents the estimated average fabric on one outcrop (see Chapter IV).

(C) Orientations of all quartz veins found in the SIC and the surrounding volcanic rocks (most veins are found within the SIC).

(D) Orientations of all blue amphibole stringer veins found in the SIC and the surrounding volcanic rocks (most veins are found within the SIC).

(E) Orientations of reliable primary bedding features found in the volcanics. These include contact horizons, interbeds and flow banding.

(F) Orientations of joints in the volcanics. These usually occur as conjugate sets and rarely penetrate into dikes or the SIC.

All values are unweighted.
Figure 3.6

(A) All Dikes

(B) All Feldspar Foliations (In SIC)

(C) Massive Quartz Veins

(D) Blue Amphibole Veins

(E) Primary Bedding in Volcanics

(F) Joints in Volcanics
Table 3.1. Minerals found in syenites. Some of the more distinctive and/or diagnostic properties of each mineral are listed.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Group</th>
<th>Formula</th>
<th>Hand Sample</th>
<th>Thin Section</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>aegirine</td>
<td>pyroxene</td>
<td>NaFe$^{3+}\text{SiO}_6$</td>
<td>black, prismatic or needle form</td>
<td>yellow-emerald green, small extinction angle</td>
<td>soda pyroxene</td>
</tr>
<tr>
<td>aegirine-augite</td>
<td>pyroxene</td>
<td>NaFe$^{3+}\text{SiO}_6$-Ca(Mg,Fe$^{2+}$,Fe$^{3+}$)\text{SiO}_6</td>
<td>dark green to black</td>
<td>bright green-brownish green, yellowish green</td>
<td></td>
</tr>
<tr>
<td>analcime (analcite)</td>
<td></td>
<td>NaAlSi$_2$O$_6$•H$_2$O</td>
<td>trapezohedral crystals in cavities or in matrix</td>
<td></td>
<td>colourless to white crystals</td>
</tr>
<tr>
<td>apatite</td>
<td></td>
<td>Ca$_5$(PO$_4$)$_3$(F,Cl,OH)</td>
<td>no cleavage</td>
<td>high relief, low birefringence</td>
<td></td>
</tr>
<tr>
<td>arfvedsonite</td>
<td>amphibole</td>
<td>Na$_3$Fe$^{2+}$Fe$^{3+}\text{SiO}_2$(OH)$_2$</td>
<td>dark green to black Na-amphibole</td>
<td>yellowish to brownish green to violet</td>
<td>s.s. with eckermannite</td>
</tr>
<tr>
<td>biotite</td>
<td></td>
<td>K$<em>2$Mg$</em>{6-x}$Al$<em>x$Si$</em>{10-x}$O$_{22}$(OH)$_2$</td>
<td>brown-black, good cleavage</td>
<td>strong pleochroism</td>
<td></td>
</tr>
<tr>
<td>cancrinite</td>
<td>feldspathid</td>
<td>Na$_6$Ca(CO$_3$)(AlSiO$_4$)$_6$•H$_2$O</td>
<td>white to yellow, prismatic cleavage</td>
<td>colourless</td>
<td></td>
</tr>
<tr>
<td>diopsie</td>
<td>pyroxene</td>
<td>CaMgSi$_2$O$_6$</td>
<td>dark green</td>
<td>green-yellow/green pleo.</td>
<td></td>
</tr>
<tr>
<td>eckermannite</td>
<td>amphibole</td>
<td>Na$_3$Mg$_3$Al$<em>6$Si$</em>{22}$(OH)$_2$</td>
<td>dark bluish green</td>
<td>pale bluish green</td>
<td>solid solution with arfvedsonite</td>
</tr>
<tr>
<td>eudialyte</td>
<td></td>
<td>(Na$_2$Ca$_x$Fe$_y$)$_6$Zr(SiO$_3$)$_6$(OH,Cl)</td>
<td>pink to cherry red</td>
<td>colourless</td>
<td>cyclosilicate, REEs</td>
</tr>
<tr>
<td>ferro-pargasitic</td>
<td>amphibole</td>
<td>Ca$_3$(Na,K)(Fe$^{3+}$,Mg,Fe$^{2+}$)$_5$(Si,Al)$<em>3$O$</em>{22}$ (OH)$_2$</td>
<td>black Na-Fe hornblende</td>
<td>orange</td>
<td></td>
</tr>
<tr>
<td>hornblende</td>
<td></td>
<td>NaCa$_2$Fe$_4$(Al,Fe)Al$_2$Si$<em>6$O$</em>{22}$(OH)$_2$</td>
<td>dark green, black</td>
<td>yellow-green, blue-green</td>
<td></td>
</tr>
<tr>
<td>hastingsite</td>
<td>amphibole</td>
<td>Ca$_3$(Na,K)$_3$(Mg,Fe$^{2+}$,Fe$^{3+}$,Al)$_3$(Si,Al)$<em>8$O$</em>{22}$(OH,F)$_2$</td>
<td>dark green, black</td>
<td></td>
<td></td>
</tr>
<tr>
<td>kaersutite</td>
<td>amphibole</td>
<td>(Na,K)Ca$_3$(Mg,Fe$^{2+}$,Fe$^{3+}$,Al)$_4$(Ti,Fe$^{3+}$) [Si$_6$Al$<em>2$O$</em>{22}$] (O,OH,F)$_2$</td>
<td>brown-black, reddish brown</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral</td>
<td>Group</td>
<td>Formula</td>
<td>Hand Sample</td>
<td>Thin Section</td>
<td>Notes</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------</td>
<td>----------------------------------</td>
<td>--------------------------------------------------</td>
<td>--------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>leucite</td>
<td>feldspathid</td>
<td>KAlSi$_2$O$_6$</td>
<td>white to pale trapezohedral crystals</td>
<td>high refractive index</td>
<td>complex twinning common</td>
</tr>
<tr>
<td>melanite</td>
<td>garnet</td>
<td>Ca$_3$Fe$_2$(SiO$_4$)$_3$</td>
<td>yellow to brown to grayish green</td>
<td>uniaxial colourless</td>
<td>Ca-Al-Mg silicate</td>
</tr>
<tr>
<td>muscovite</td>
<td></td>
<td>KAl$_2$(AlSi$_3$O$_10$)(OH)$_2$</td>
<td>colourless</td>
<td>high birefringence</td>
<td></td>
</tr>
<tr>
<td>natrolite</td>
<td>zeolite</td>
<td>Na$_2$Al$_2$Si$_3$O$_10$·2H$_2$O</td>
<td>colourless if pure</td>
<td></td>
<td>orthorhombic</td>
</tr>
<tr>
<td>nepheline</td>
<td>feldspathid</td>
<td>(Na, K)AlSiO$_4$</td>
<td>poor cleavage, colourless, white, grey</td>
<td></td>
<td>weathers easily</td>
</tr>
<tr>
<td>nosean</td>
<td>feldspathid</td>
<td>Na$_8$[Al$_6$Si$<em>6$O$</em>{24}$]SO$_4$</td>
<td>grey, brown or blue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>phlogopite</td>
<td></td>
<td>KMg$_3$(AlSi$_3$O$_10$)(OH)$_2$</td>
<td>yellowish-brown</td>
<td>lighter than biotite</td>
<td></td>
</tr>
<tr>
<td>pyrope</td>
<td>garnet</td>
<td>Mg$_3$Al$_2$Si$_3$O$_12$</td>
<td>purple</td>
<td></td>
<td>isotropic</td>
</tr>
<tr>
<td>ramsayite</td>
<td></td>
<td>Na$_2$Ti$_2$Si$_2$O$_9$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>riebeckite</td>
<td>amphibole</td>
<td>Na$<em>2$Fe$</em>{3+}$Fe$_{3+}$Si$<em>6$O$</em>{22}$(OH)$_2$</td>
<td>blue to black needle or fibrous form</td>
<td>yellow to orange</td>
<td></td>
</tr>
<tr>
<td>sodalite</td>
<td>feldspathid</td>
<td>Na$_6$(AlSiO$_4$)$_2$Cl$_2$</td>
<td>white to blue, vitreous, translucent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>spinel</td>
<td>spinel</td>
<td>MgAl$_2$O$_4$</td>
<td>colourless, red, blue, brown, etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>titanaugite</td>
<td>pyroxene</td>
<td>(Ca, Na)(Mg, Fe$_{2+}$, Ti, Fe$^{3+}$, Al)(Si, Al)$_2$O$_6$</td>
<td>stronger colours than augite</td>
<td>violet pleochroism</td>
<td>zoning common</td>
</tr>
<tr>
<td>titanite (sphene)</td>
<td></td>
<td>CaTi[SiO$_4$](O, OH, F)</td>
<td>yellow or brown; high birefringence</td>
<td></td>
<td>diamond shaped crystals</td>
</tr>
</tbody>
</table>
Table 3.2. Names of the six major facies found within the SIC; with equivalent abbreviations, and IUGS rock names of representative members of each facies.

<table>
<thead>
<tr>
<th>Facies</th>
<th>Abbreviation</th>
<th>IUGS Name of Representative Rock*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotite Pyroxene Syenite</td>
<td>BPS</td>
<td>Sphene-bearing biotite aegirine-augite syenite</td>
</tr>
<tr>
<td>Biotite Amphibole Syenite</td>
<td>BAS</td>
<td>Rutilated-biotite riebeckite syenite</td>
</tr>
<tr>
<td>Pyroxene Amphibole Syenite</td>
<td>PAS</td>
<td>Riebeckite aegirine-augite syenite</td>
</tr>
<tr>
<td>Green Amphibole Syenite</td>
<td>GAS</td>
<td>Alkali amphibole (microcline) syenite</td>
</tr>
<tr>
<td>Quartz Phytic Syenite</td>
<td>QPS</td>
<td>Quartz phytic syenite</td>
</tr>
<tr>
<td>Amphibole Quartz Syenite</td>
<td>AQS</td>
<td>Amphibole bearing quartz syenite</td>
</tr>
</tbody>
</table>

All facies possess feldspar-megacrystic textures.

* IUGS recommended (1976) name for a rock which is considered to be representative of the facies.
- - - - - - - - - - - - - JavO
- 1 I J O
sanbedo
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2
2
1
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------------ zwnb
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SP ZP SE
oz SI s
oz Pl s
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O Z O
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'07 *!H A

OS

x!JlQq

X!JWly

LP-C

s$srli~a8a~

X!JSW

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s)shwSa];y

*mdsplad-~
lBJ3U!M


Table 3.3. (Continued). Modal mineral compositions (volume percentage) for facies found within the SIC.

<table>
<thead>
<tr>
<th>Facies</th>
<th>QPS</th>
<th>AQS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Megacrysts</td>
<td>Matrix</td>
</tr>
<tr>
<td>K-Feldspar*</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pyroxene</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Biotite</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Amphibole</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Quartz</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Titanite</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Apatite</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Opaques</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

All values are % modal composition. t denotes trace amounts in the mode. *Most K-feldspars are perthites.
Table 3.4. Table of feldspar megacryst characteristics for all Facies Groups.

<table>
<thead>
<tr>
<th>Facies</th>
<th>Common Shape</th>
<th>Proposed Habit</th>
<th>Megacryst Size* (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Primary</td>
<td>Other</td>
</tr>
<tr>
<td>BPS</td>
<td>tabular</td>
<td>Finisterre</td>
<td>Baveno</td>
</tr>
<tr>
<td>BAS</td>
<td>tabular</td>
<td>Finisterre</td>
<td>-</td>
</tr>
<tr>
<td>PAS</td>
<td>sub-equant</td>
<td>Orthoclase</td>
<td>Finisterre</td>
</tr>
<tr>
<td>GAS</td>
<td>sub-equant</td>
<td>Orthoclase</td>
<td>Finisterre</td>
</tr>
<tr>
<td>QPS</td>
<td>sub-equant</td>
<td>Orthoclase</td>
<td>Finisterre</td>
</tr>
<tr>
<td>AQS</td>
<td>sub-equant</td>
<td>Orthoclase</td>
<td>Finisterre</td>
</tr>
<tr>
<td>BPD</td>
<td>tabular</td>
<td>Finisterre</td>
<td>Orthoclase</td>
</tr>
<tr>
<td>BAD</td>
<td>tabular</td>
<td>Finisterre</td>
<td>Orthoclase</td>
</tr>
<tr>
<td>AQD</td>
<td>sub-equant</td>
<td>Orthoclase</td>
<td>Finisterre</td>
</tr>
<tr>
<td>QFD</td>
<td>tabular</td>
<td>Finisterre</td>
<td>Orthoclase</td>
</tr>
<tr>
<td>QAD</td>
<td>tabular</td>
<td>Finisterre</td>
<td>-</td>
</tr>
</tbody>
</table>

* Size refers to longest dimension of feldspar megacryst.

Table 3.5. Names of the five major dike facies found within and/or outside the SIC; with equivalent abbreviations, and IUGS rock names of representative members of each facies. The abbreviations for proposed petrologic equivalent SIC facies are also listed.

<table>
<thead>
<tr>
<th>Facies</th>
<th>Acronym</th>
<th>IUGS Name of Representative Rock*</th>
<th>Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotite Pyroxene Dike</td>
<td>BPD</td>
<td>Biotite augite trachyte</td>
<td>BPS</td>
</tr>
<tr>
<td>Biotite Amphibole Dike</td>
<td>BAD</td>
<td>Quartz bearing biotite amphibole trachyte</td>
<td>BAS</td>
</tr>
<tr>
<td>Amphibole Quartz Dike</td>
<td>AQD</td>
<td>Amphibole bearing quartz trachyte</td>
<td>AQS</td>
</tr>
<tr>
<td>Quartz Feldspar Dike</td>
<td>QFD</td>
<td>Quartz-feldspar-phryc trachyte</td>
<td>none</td>
</tr>
<tr>
<td>Quartz Amphibole Dike</td>
<td>QAD</td>
<td>Amphibole quartz-phryc k-feldspar rhyolite</td>
<td>none</td>
</tr>
</tbody>
</table>

All facies are feldspar-phryc.

* IUGS recommended (1976) name for a rock which is considered to be representative of the dike facies.
Table 3.6. Modal mineral compositions (volume percentage) for dike facies.

<table>
<thead>
<tr>
<th>Facies</th>
<th>BPD</th>
<th></th>
<th>BAD</th>
<th></th>
<th>AOD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Megacrysts</td>
<td>Matrix</td>
<td>Megacrysts</td>
<td>Matrix</td>
<td>Megacrysts</td>
</tr>
<tr>
<td>K-Feldspar*</td>
<td>5</td>
<td>30</td>
<td>60</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pyroxene</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Biotite</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Amphibole</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>t</td>
</tr>
<tr>
<td>Quartz</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>t</td>
</tr>
<tr>
<td>Titanite</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Apatite</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>t</td>
<td>t</td>
</tr>
<tr>
<td>Opaques</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Facies</th>
<th>QFD</th>
<th></th>
<th>QAD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Megacrysts</td>
<td>Matrix</td>
<td>Megacrysts</td>
</tr>
<tr>
<td>K-Feldspar*</td>
<td>20</td>
<td>60</td>
<td>85</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>5</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Pyroxene</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Biotite</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Amphibole</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Quartz</td>
<td>5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Titanite</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Apatite</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Opaques</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

All values are % modal composition. **t** denotes trace amounts in the mode. *Most K-feldspars are perthites.*
Plate 3.1. Syenite Intrusive Complex: contacts.

(A) Outcrop exposure of volcanic xenoliths (v) in biotite pyroxene syenite (s), near the main contact between the SIC and the host volcanic pile. Note the conjugate joint sets in the volcanics, which rarely penetrate the syenite material. (The joints in the two volcanic xenoliths in the foreground possess contiguous joint orientations). Lens cap is 55mm in diameter. Photograph is of a horizontal surface. Location: Mill Hill contact zone.

(B) Outcrop exposure of an internal contact between two different SIC facies. The lower portion of the photograph consists of a quartz-phyric syenite, in sharp contact (arrows) with a green amphibole syenite. Note the mafic enclave (m). Photograph is of a horizontal surface. The upper scale of the ruler is marked in centimetres and millimetres. Location: outcrop 7/9-5.

(C) Scanned thin section of a pyroxene amphibole syenite (PAS) cut by a later biotite pyroxene dike (BPD). Left side of image is a PAS, containing (r) primary riebeckite and (s) an alteration stringer. The dike contact runs from top to bottom of image centre; disconcordantly cutting the foliation of the host and its individual feldspars. Note the differences between feldspars in both facies types. Width of field is 60mm. Sample 6/15-1/1; XPL.

(D) The same section as (C), in PPL. The dike exhibits margin parallel mafic poor zones (arrows). Width of field is 60mm. Sample 6/15-1/1; PPL.
Plate 3.2. Biotite Pyroxene Syenites (BPS): mineralogy and textures.

(A) Scanned thin section of a high feldspar content BPS. Euhedral feldspars are closely packed together and a moderately well developed SPO [3] runs approximately parallel to diagonal of photo. Note the dusty sericitic alteration of megacrysts. Section is cut perpendicular to foliation defined by the feldspars. Width of field is 55 mm. Sample 6/15-2/3; PPL.

(B) Polished slab of fine to medium grained seriate BPS. Euhedral feldspars are typically non-interfering, and float freely in a matrix of fine-grained pyroxene and biotite. Slab is cut perpendicular to a strong SPO foliation. Note the ‘T-structure’ formed by a feldspar megacryst that is perpendicular to the dominant SPO (centre-top of image), and the related deflection of the surrounding fabric. Sample 6/18-1/3.

(C) Thin section micrograph of a perthite grain in BPS. The yellow material consists of optically continuous rods and blebs of albite (the section is slightly thick). Arrows indicate patches of orthoclase with the characteristic tweed pattern (albite and pericline twin laws). The width of field is 2.5 mm. Sample 6/15-2/3; XPL.

(D) Thin section micrograph dominated by the end of a perthite grain in a BPS. The arrows indicate the termination of the grain. Albitization is most extensive near these outer edges of the grain. The optically continuous, irregular material at extinction is orthoclase. The width of field is 2.5 mm. Sample 8/24-5/2; XPL.

(A) Thin section micrograph of a coarse grained BPS from the Mill Hill contact location. The large grain in the centre of the field is a (discontinuous) compositionally zoned clinopyroxene; possessing an augite core surrounded by an aegirine-augite rim. The width of field is 10 mm. Sample EP2; PPL.

(B) Thin section micrograph of the same sample as in (C). The aegirine-augite grain at the centre of the field exhibits oscillatory zoning (arrow). Note the secondary fibrous blue amphibole on the pyroxene grain in the left centre of the field. The width of field is 10 mm. Sample EP2; PPL.

(C) Thin section micrograph of several rutile-tared biotite grains in a BPS. Most of the greenish-brown biotite grains exhibit their basal sections and contain abundant optically oriented rutile needles (arrow: r). The light green grains are pyroxene, and the colourless areas are anhedral, interstitial feldspar. Titanite grains (t) are common in this facies type. The width of field is 2.5 mm. Sample 7/19-1; PPL.

(D) Thin section micrograph of the same sample of BPS seen in (C). An euhedral titanite grain, common to this facies, dominates the centre of the field. The remainder of the field contains pyroxene, biotite and feldspar. Note the perthite grain poikilitically enclosing some of the mafics on the right hand side of the field. The width of field is 2.5 mm. Sample 7/19-1; PPL.
Plate 3.4. Biotite Pyroxene Syenites (BPS): textures.

(A) Thin section micrograph of a very coarse grained, high feldspar content BPS. Euhedral feldspars are closely packed together. Late stage growth of the feldspar crystals has yielded an overgrowth or poikilitic enclosure of pyroxene and biotite grains (arrow 1), as well as fusing of the feldspar grains (arrow 2). Section is cut perpendicular to foliation defined by the feldspars. Note the Carlsbad twin contact plane, and overgrown feldspar crystal (arrow 3) in the lowermost feldspar megacryst. The width of field is 10 mm. Sample 7/19-1/5; XPL.

(B) Thin section micrograph of a coarse grained, high feldspar content BPS. Feldspar megacrysts dominate this rock and exhibit fused face-to-face contacts. The contacts are highlighted by a lack of sericitic alteration of the albitic material forming the margins of the megacrysts. Carlsbad twins are easily identified in many of these megacrysts. The width of field is 10 mm. Sample 6/12-H2.

(C) Polished slab of a medium to very coarse grained seriate BPS. A moderately well developed [3] SPO runs parallel to the width of the micrograph. Arrows indicate bent grains at a high angle to the SPO. Compare the deceptive appearance of the megacryst faces with those in (D), which is a micrograph of the same sample. Scale bar is 2 cm long. Sample 7/19-1/4.

(D) Thin section micrograph of the same sample as in (C). The bent grain in the middle of the field appears to have behaved plastically. Feldspar megacrysts exhibit typical poikilitic margins and Carlsbad twins. Note the late anhedral feldspar filling the intergranular voids between mafics (arrow). The width of field is 10 mm. Sample 7/19-1/4; XPL.
Plate 3.5. Biotite Pyroxene Syenites (BPS): varieties and fabrics.

(A) Polished slab of a coarse grained, 'prismatic' BPS variety. Euhedral feldspars are triaxial but possess an overall aspect ratio that is essentially prismatic, unlike the tabular crystals that dominate most occurrences of BPS rocks. The slab is cut perpendicular to a linear SPO defined by the long axes of the feldspar grains. Most of the feldspar grains are therefore cut perpendicular to their long axes, showing only their lesser axes (arrow 1). Several grains are rotated oblique to this lineation, yielding sections parallel to their long axes (arrow 2). Note that these oblique grains also define their own lineation, trending from top to bottom of the photograph. Sample 8/28-2/4.

(B) Outcrop exposure of a BPS with a bimodal size range of feldspar megacrysts (arrows indicate large phenocrysts). A strong SPO runs parallel to the width of field. Photograph is of a horizontal surface. Ruler is marked in centimetres and millimetres. Location: outcrop 6/15-2.

(C) Thin section micrograph of a very coarse grained BPS. A strong SPO runs parallel to the width of the micrograph. The elongate pyroxene grains are oriented parallel to the feldspar SPO (arrows). Note the patchy sericitic alteration in the feldspar megacrysts (f). The width of field is 10 mm. Sample 7/13-2/1; PPL.

(D) Thin section micrograph of mafic matrix in a BPS with a strong feldspar defined SPO (double-headed arrow). Elongate biotite grains (arrows) are oriented parallel to the dominant feldspar defined SPO. The large pyroxene grain in the centre of the image is compositionally zoned. The width of field is 2.5 mm. Sample 6/18-1/3; XPL.
Plate 3.6. Biotite Amphibole Syenite (BAS) and Pyroxene Amphibole Syenite (PAS).

(A) Scanned thin section of a very high feldspar content BAS. This rock exhibits textures and fabrics similar to those found in the BPS. Arrows indicate grain-to-grain margins of perthitic feldspar megacrysts, and poikilitic enclosure of euhedral amphibole grains. There is an unusual intergrown t-shaped grain (twin?) in the centre of the image (t). The width of field is 55 mm. Sample 6/25-7/2; PPL.

(B) Thin section micrograph of the sample in (A). This section is cut perpendicular to a lineation defined by the preferred orientation of prismatic amphibole grains. Amphiboles in this image typically exhibit this orientation (i.e. they are cut perpendicular to their long axes). Width of field is 55 mm. Sample 6/25-7/2; PPL.

(C) Outcrop exposure of a PAS. Alkali feldspar megacrysts are tightly packed with an interstitial matrix of coarse alkali amphiboles. A moderate SPO runs parallel to the width of field. Diameter of coin is 21 mm. Location: outcrop 7/9-10.

(D) Scanned thin section of a very high feldspar content BAS. Arrows indicate large alkali amphibole grains. The brown grains are amphiboles cut perpendicular to their long axes. The darker clots are subhedral to euhedral pyroxene grains. The dominant, sericitic feldspar grains exhibit fused margins and poikilitic enclosure of matrix grains. The width of field is 55 mm. Sample 7/9-10A1; PPL.
Plate 3.7. Green Amphibole Syenite (GAS): mineralogy and textures.

(A) Polished slab of a coarse grained, GAS. Feldspar megacrysts are euhedral with very sharp margins, but often fragmented and/or embayed (arrows). Fragmented grains are easily identified by a truncation of the very well developed rhythmic zoning of the feldspars. Sample 7/9-5B2.

(B) Thin section micrograph of the same sample as in (A). A large euhedral feldspar grain on the right hand edge of the field exhibits zoning defined by trains of feldspar microlites. The fragmented and embayed nature of the feldspar megacrysts is clearly visible. Note the relict pyroxene megacryst (arrow). The width of field is 10 mm. Sample 7/9-5B2; XPL.

(C) Thin section micrograph of the same sample as in (A), highlighting a dramatic embayment of a zoned feldspar megacryst, with a matrix infill. Trains of anhedral feldspar microlites define the zoning in the feldspar grains (arrow). The width of field is 10 mm. Sample 7/9-5B2; XPL.

(D) Thin section micrograph of the feldspar grain exhibited in (C) at a higher magnification. Magnified (and rotated 90° clockwise) view of the embayment ‘neck’, indicates a similarity in matrix mineralogy composition but a difference in matrix grain size on either side of the opening. The material inside the cavity (1) has a larger mean grain size than the material found outside the cavity (2). The width of field is 2.5 mm. Sample 7/9-5B2; XPL.

(A) Thin section micrograph of an unusual feldspar megacryst in a GAS. This crystallographically continuous orthoclase grain exhibits an unusual centre (embayment?) containing anhedral plagioclase grains. The width of field is 2.5 mm. Sample 7/11-2/2.

(B) Scanned thin section of a mafic enclave in a green amphibole syenite (GAS). The image consists mostly of a mafic enclave material in contact (arrow) with typical GAS. Both contain broken and heavily corroded feldspar megacrysts. Note the difference in the size of the groundmass grains between the two varieties. Width of field is 55 mm. Sample 6/30-5/3; XPL.

(C) Thin section micrograph of a GAS mafic enclave. The amphibole needles in the matrix exhibit a strong SPO texture (lineation), which is seen here deflected around a fragmented and embayed feldspar grain. Note the pyroxene grain in the ‘centre’ of the feldspar. This grain appears to have been at the core of the feldspar prior to embayment. The width of field is 10 mm. Sample 6/30-5/3; PPL.

(D) Thin section micrograph of the contact in (B). The mafic enclave in the lower portion of the image appears to have behaved plastically in contact with the normal GAS material. Note the indentation in the enclave matching the profile of a large feldspar grain (arrow). The width of field is 10 mm. Sample 6/30-5/3; XPL.
Plate 3.9. Quartz Phryic Syenite (QPS).

(A) Thin section micrograph of a typical QPS. This rock exhibits textures and fabrics similar to those found in the GAS. Fragmented and/or embayed feldspar megacrysts (arrows), as well as embayed quartz megacrysts (centre of image), are visible. Note the extensive embayment of the optically continuous feldspar in the bottom left of the field. The anomalous interference colours in the quartz grain in the lower right of the field are caused by improper section thickness). The width of field is 10 mm. Sample 7/9-5B1; XPL.

(B) Thin section micrograph of the same sample as in (A), showing extensively embayed quartz megacrysts (arrows). Section is too thick. The width of field is 10 mm. Sample 7/9-5B1; XPL.

(C) Thin section micrograph of the same sample as in (A), showing a rhythmically zoned euhedral quartz megacryst. This is the same grain that is seen in the centre of (A). The crystal is near extinction, highlighting the trains of anhedral crystallites (of unknown composition) that define the zoning. Width of field is 2.5 mm. Sample 7/9-5B1; XPL.
Plate 3.10. Amphibole Quartz Syenite (AQS): mineralogy, textures, and fabrics.

(A) Scanned thin section of an amphibole quartz syenite (AQS). Image is dominated by euhedral zoned perthites and interstitial quartz. Note the curved crystal faces and unusual extinction figures of some of the megacrysts (arrows). Some grains exhibit slight damage or indentation at point to face contacts. Thin section is slightly thick; width of field is 60 mm. Sample 7/3-1/1; XPL.

(B) Thin section micrograph of the sample in (A). Feldspar megacrysts are in point to point contract. Note the curved crystal faces and unusual extinction figures. Anhedral quartz grains fill interstitial voids. Thin section is slightly thick; width of field is 10 mm. Sample 7/3-1/1; XPL.

(C) Thin section micrograph a feldspar megacryst with unusual extinction figure. (See (D)). Thin section is slightly thick; width of field is 10 mm. Sample 7/3-1/1; XPL.

(D) Thin section micrograph of the same grain seen in (C) but rotated counterclockwise 15°. Compare to image (C) and note the movement of the extinction figure, which is similar to the sweeping of isogyres in conoscopic viewing of some minerals. Thin section is slightly thick; width of field is 10 mm. Sample 7/3-1/1; XPL.
Plate 3.11. Biotite Pyroxene Dikes (BPD) and Quartz Feldspar Porphyry Dikes (QFD): mineralogy, textures, and fabrics.

(A) Scanned thin section of a BPD. Zoned and partially fragmented euhedral feldspars float in matrix. Note the rare fracture with a sense of offset given by the broken feldspar grain (arrow). Section is cut perpendicular to foliation and lies in the horizontal plane of the original exposure. Width of field is 58 mm. Sample G9/8-1E; XPL.

(B) Thin section micrograph of the sample in (A). Zoned, euhedral feldspar phenocrysts are floating in matrix and possess sharp margins. The arrow indicates an accessory apatite grain. Note the large damaged pyroxene grain on the right edge of the field. Width of field is 10 mm. Sample G9/8-1E; XPL.

(C) Thin section micrograph of a QFD. A malformed but euhedral quartz grain contains an inclusion rich rim. Note the albite grains in the matrix. Width of field is 10 mm. Sample 6/18-1/1; XPL.

(D) Thin section micrograph of a QFD. The centre of the field is dominated by an unusual feldspar with large face parallel inclusions and a core of matrix(?) material. Width of field is 10 mm. Sample 6/18-1/1; XPL.

(A) Scanned thin section of a quartz amphibole dike (QAD). The host rock is a biotite pyroxene syenite with minor secondary blue amphibole. Large feldspar megacrysts line the walls of the dike (f). Note that these feldspars appear to be the same as the smaller megacrysts found within the interior of the dike. The section is cut perpendicular to the strike length of the dike, and the top profile of the section is the original outcrop erosional profile. Width of field is 65 mm. Sample 6/21-4/1; PPL.

(B) Thin section micrograph of the sample in (A). Zoned, subhedral to euhedral quartz phenocrysts and glomerocrysts are floating in a matrix of polygranular feldspar and amphiboles. Width of field is 2.5 mm. Sample 6/21-4/1; PPL.

(C) Thin section micrograph of the sample in (A) showing detail of quartz zonation. Zoning is due to trains of alkali amphibole needles lying parallel to crystal faces of the quartz grain. A lower concentration of needles at crystal face interstices yields an asterism in some hand sample quartz grains. Width of field is 2.5 mm. Sample 6/21-4/1; XPL.
Plate 3.13. Cross-cutting relationships.

(A) Outcrop exposure exhibiting cross-cutting relationships within the SIC. A coarse grained BPS dike with irregular margins cuts a very coarse-grained BPS. Note the truncation of the well-developed foliation in the latter (parallel to the width of the photograph). Truncated feldspars in the host are common at the dike margins (arrow). Diameter of lens cap is approximately 55 mm. Location: outcrop 8/30-1/1.

(B) Outcrop exposure exhibiting cross-cutting relationships within the SIC. A large exposure of PAS (a) is cut by a narrow dike of the AQD facies (b). Both are in turn cut and offset by a green QAD facies dike (c). The main QAD dike runs parallel to the height of the photograph, while apophyses are concordant with the contact between PAS and AQD. Length of ruler is approximately 17 cm. Location: Lucky Swine Exposure, outcrop 7/9-1.

(C) Outcrop exposure exhibiting cross-cutting relationships within the SIC. A green quartz amphibole dike (QAD) cuts a body of quartz phryic syenite (QPS). Both are in turn cut by a late massive quartz vein. Diameter of coin is 21mm. Location: outcrop 7/9-5.

(D) Outcrop exposure of more cross-cutting relationships found within the SIC. A stringer vein of fibrous blue amphibole cuts the same quartz vein that is seen in (C). This particular blue vein is unusually sharp. Note the feldspars visible within its margins. Diameter of coin is 21mm. Location: outcrop 7/9-5.
CHAPTER IV: SHAPE PREFERRED ORIENTATIONS OF MINERAL GRAINS IN THE ALDERMAC SYENITE IGNEOUS COMPLEX AND DIKES

ABSTRACT

Outcrop and map scale analyses of Shape-Preferred Orientation (SPO) defined fabrics were carried out on the dominantly tabular bodies of the Aldermac Syenite Igneous Complex (SIC) and its related dikes. Most of these rocks, with megacryst fractions varying from 10 to 75 volume %, exhibit very strong SPOs of these megacrysts. The most common SPOs consist of foliations and/or lineations parallel to the intrusive contacts of tabular bodies. But another SPO, commonly found in dikes, consists of megacrysts outlining concentric circles, often spanning the width of the dike. Results of the analyses indicate that:

1. The SPO fabrics within the SIC do not record a strain field associated with any diapiric rise of the magma.
2. Current models for the acquisition of igneous SPO fabrics in dikes do not account for many of the observed fabrics.
3. The SPO fabrics at Aldermac may record a continuous progression of magma transport.

In order to explain the strong SPOs observed at Aldermac, we propose the combination of two phenomena. One is the inhibition of movement of megacrysts as they are ‘captured’ by the current margin of active flow in a tabular body, or as they are trapped within a high density of megacrysts. The term capture is used in a sense different from that of Marsh (1988). The second phenomenon is filter-pressing (e.g. McKenzie, 1987; Higgins, 1991), wherein the fraction of the magma that still behaves as a low viscosity liquid is decoupled (fractionated) from the mechanically trapped megacrysts as the body deflates.

INTRODUCTION

As part of a study of the igneous rocks found at the Aldermac mine site, an analysis of mineral defined shape preferred orientations (SPO) fabrics was completed on the Syenite Igneous Complex (SIC) and its related dikes. The outcrop and map-scale data presented
here will expand on the detailed petrographic descriptions and fabrics identified in thin section and hand samples in Chapter III. The crystal SPO fabrics are compiled and presented in order to test their usefulness as magma flow indicators, and as tools to help elucidate the emplacement history of the intrusive rocks at Aldermac.

Most of the intrusive rocks at Aldermac occur as bodies with tabular morphologies. These include thick tabular bodies, multiple parallel sheets, or high aspect ratio dikes. As a result of this similarity in intrusive morphologies, the current models for flow and emplacement of magma in dikes provides a useful starting point for analysing the fabrics found at Aldermac.

Flow and Flow Direction Indicators in Dikes, A Review

A dike is defined as a sheetlike (tabular) intrusion of magma that cuts at a high angle across bedding or foliation in a country rock (Suppe, 1985). Dikes are ubiquitous occurrences in the earth’s crust, and may provide the transport mechanism for other igneous intrusions such as plutons and batholiths. By definition a dike has two roughly parallel confining margins. Thus, in studying the ascent and emplacement of magma in an igneous body, a dike appears to provide one of the simplest end-member models for theoretical and field analysis of fabrics and textures as magma flow indicators.

In determining the flow or transport history of a dike, a starting method can involve the study of the overall dimensions and field relationships of a dike (Shelley, 1985). In volcanic terranes, dikes radiating from a volcanic centre may give some indication that flow proceeded away from the volcano, but this is not a fixed rule (Sanderson, 1982). For most other occurrences of dikes and neighbouring igneous bodies such as plutons, the relationships between the two may be very difficult to determine. Where dikes radiate off of a plutonic centre it is even debatable whether the pluton provided the source material for the dikes, or the dikes sourced the pluton.

Fabrics and Textures as magma flow indicators

Fabrics or textures commonly found near the margins of a dike, such as margin-parallel orientations of mafic or felsic wisps and stretched vesicles have long been used to establish bidirectional flow lines in dikes (Roberts and Sanderson, 1971; Smith, 1978;
Shelley, 1985). Problems inherent in the interpretations of these phenomena include the lack of any sense of direction of movement along the flow line (i.e. a unique flow direction is not known), and the fact that these marginal flow lines may not represent the state of flow in the centre of the dike (Shelley, 1985). The anisotropy of magnetic susceptibility (AMS) method has also been used to determine flow lines in dikes (Ellwood, 1978), but this method can also yield ambiguous bidirectional flow lines (Shelley, 1985). Interpretations of AMS fabrics must also be tempered with the knowledge that AMS fabrics are likely to be acquired late in a dike’s history – recording only that stage of magma transport (Canon-Tapia et al., 1995).

Skinner (1990) lists some useful unidirectional flow indicators found in the walls of dikes, including apophyses, drag folds, scour marks and steps. Other widely accepted indicators of flow direction include (Philpotts and Asher, 1994):

1. Broken and sheared phenocrysts yielding flow direction from the sense of shear of the fragments (Figure 4.1B).
2. Felsic or mafic wisps stretched and/or folded by magma flow (at an angle to the dike walls) (Figure 4.1C).
3. Segregations on opposing corners of phenocrysts (Figure 4.1D).
4. Groundmass shear zones (Figure 4.1E).

Coward (1980) and Canon-Tapia et al. (1995) have documented distinctive curved and/or conical patterns of strained vesicles in basaltic dikes, which yield unique flow directions. Unfortunately most of the above phenomena are relatively uncommon. Where these useful unidirectional flow indicators are absent, most of the work involved in reconstructing the flow of magma in a dike (and the direction of initial propagation) has been focused on the orientation of igneous megacrysts within the magma.

**Igneous Shape-Preferred Orientations**

The main criteria for interpretation of suspension-like flow of magma are fabrics defined by shape-preferred orientations (SPO) of primary igneous minerals. Fernandez (1987) defines these as “the orientation of significant morphologic elements of a crystal”, i.e. the (010) planes of a feldspar grain or the c-axes of elongate amphiboles. Common SPO fabrics include lineations defined by the long axes of elongate mineral grains, and
foliations defined by the parallel arrangement of the large faces of flat particles (Figure 3.1). Attempts to quantify observations of SPOs have looked to theoretical modelling of the mechanical behaviour of rigid particles in a flowing viscous matrix. The literature on the theoretical study of particle orientation in a flowing matrix, the study of SPO fabrics in real rocks, and the combination of the two fields is extensive (e.g. Jeffery, 1922; Bhattacharyya, 1966; Den Tex, 1969; Ghosh and Ramberg, 1976; Paterson *et al.*, 1989; Fernandez and Laporte, 1991; Ildefonse *et al.*, 1992; Jezek *et al.*, 1994).

**The Jeffery Model**

The conceptualisation of primary igneous flow fabrics was first thoroughly treated by Bhattacharyya (1966) and Den Tex (1969). They noted that large crystal faces of anisotropic minerals oriented themselves to offer the least resistance to magma flow. In models of homogeneous two-dimensional flow near dike margins, simple shear of the magma causes rigid megacrysts to rotate (Ildefonse and Fernandez, 1988). The Jeffery (1922) rotation model indicates that the relative rotation rate of an isolated rigid ellipsoid is greatest when its long dimension is perpendicular to the simple shear direction of the flow (more exactly, when its area projected along the direction of simple shear is maximum), and smallest when that long dimension is parallel to the shear direction. For a magma with multiple rigid markers (megacrysts), in principle, there should therefore result a preferred orientation of the long axes of the megacrysts parallel to the plane of simple shear (Benn and Allard, 1989; Nicolas, 1992). The above argument assumes that the megacrysts are in a viscous matrix and do not interact with each other, thus allowing for free rotation of grains. It should be noted that this model is two-dimensional and that there is as yet, no complete general three-dimensional solution to this problem. Furthermore the assumptions of rigid ellipsoids may not be valid for the rectangular parallelepipeds of the same ratio, which are a more realistic approximation of the shape of many igneous megacrysts (i.e. feldspars).

Comparison of field evidence with experimental work involving particle suspensions has shown that a simplified model of two-dimensional laminar flow by simple shear with Jeffery-style rotation of megacrysts, may not be adequate in explaining groundmass and megacryst alignment fabrics (Bergantz and Dawes, 1994). For ellipsoids
with axial ratios similar to those of common igneous megacrysts, the Jeffery rotation model predicts an SPO that is much weaker than the SPOs often found in real rocks. Complications arise when grains are in contact and/or of differing sizes (Nicolas, 1992), and when the nature of the matrix between the grains is considered (e.g. slipping versus non-slipping interfaces) (Ildefonse and Mancktelow, 1993; Jezek et al., 1994).

**Timing of fabric acquisition**

Consideration must also be given to the possibility that in real rocks some SPO fabrics may not record the history of the earliest intrusion and transport of magma, and may only represent phenomena that took place during the most recent state of flow. Some of these phenomena may include magma pulses, changes from vertical to lateral flow and backflow (Philpotts and Asher, 1994). Furthermore, the fabrics and textures recorded in a dike may have formed during any part of a continuum between magmatic and solid-state processes operating during the history of the dike (Paterson et al., 1989). Thus the external morphology and internal petrologic structure of a dike may preserve one, or numerous events of flow direction and flow intensity, as well as fabrics related to processes occurring during the earliest transport history of magma through to late stage cooling phenomena.

**The Aldermac Syenite Igneous Complex and related Dikes**

Many of the dikes at Aldermac contain SPOs, defined by (apparently) non-interfering megacrysts, and these SPOs are much stronger than those predicted by the Jeffery-rotation model. Furthermore, many of the rocks found at Aldermac contain highly developed SPOs defined by very high modal amounts of megacrysts (e.g. 60% +). These do not fit into existing models of SPO formation based on the free rotation of particles in a viscous matrix (i.e. two-dimensional Jeffery-rotation). The fabrics of many of these high megacryst mode rocks may be related to extensive fractionation between crystals and remaining liquid up to the end of in situ crystallisation. This fractionation probably results from the expulsion of melt matrix during an in situ filter pressing event, related to the deflation of the host igneous body. The circular arrangements of feldspar megacrysts found in many of the dikes surrounding the SIC (described later in this chapter) also
suggests that the model of two-dimensional sheet flow invoked in the above discussion was not valid at least during the latest recorded history of those dikes. These circles suggest that at some (presumably late) stage, bulk transport of magma occurred along discrete linear channels.

**ANALYTICAL METHODS**

As part of the mapping project at the Aldermac Mine site, analyses were conducted on:

1. The distribution and orientations of SPO fabrics (foliations and lineations) within the map area.
2. The relationships between SPO fabrics and the intrusion contacts of their host.
3. The strength of SPO fabrics.
4. The distribution and characteristics of other SPOs such as circles and folds.

Given the wide range in the degree of development of SPOs at Aldermac, and the large number of occurrences of rocks containing those SPOs, all orientation measurements were made by visual estimation of the mean preferred orientation (PO), using a Brunton transit. Experiments designed to test the validity of this method are outlined in Appendix A3. Table 4.1 lists the six ‘standard’ field descriptions (and a numerical classification scheme) of the degree of preferred orientation seen in two-dimensional exposures at Aldermac. Appendix A3 contains an objective calibration of two of these field descriptions.

In the SIC, the number of orientations reported for an individual outcrop is typically limited to one. Outcrops which are unusually large, or which contain domains or intrusions with dramatically different SPO orientations, may have more than one recorded measurement. A more detailed fabric orientation analysis was conducted at the Lucky Swine outcrop location (Maps 1.1 and 1.3). At this exposure fabric orientations were taken (where visible) for most 5 m² patches. All fabric orientation measurements are displayed on Maps 1.1 and 1.3, with the appropriate symbols (indicated in their Legends). Compiled fabric data (unweighted) was plotted and analysed using the Spheristat 2.1 computer application.
SYENITE INTRUSIVE COMPLEX

Fabrics in the SIC
Most of the rocks of the SIC are characterised by moderate to high concentrations of particles (such as feldspar megacrysts and larger mafic minerals including pyroxenes and/or amphiboles) exhibiting strong shape preferred orientations (SPO). These SPOs define a variety of fabrics that are commonly continuous at outcrop and map scale. SPOs defined by elongate and/or flattened mafic enclaves are also found in the rocks of some facies. Enclave defined SPO fabrics may share symmetry elements with mineral defined SPO fabrics in the same rock, or they may form their own independent fabric where in the absence of megacryst fabrics.

SPO-Defined Foliations
In the SIC, a two-dimensional (horizontal) outcrop exposure will commonly yield a detectable foliation trace, defined by the preferred orientation of multiple elongate sections of feldspar grains (see face xz on Figure 4.2A and B; Plate 4.1A). Outcrops that allow for examination of a three dimensional exposure, (e.g. two mutually perpendicular outcrop faces are usually sufficient), confirm that this is the trace of a foliation defined by the preferred planar arrangement of tabular feldspar grains (see planes xz and yz on Figure 4.2A and B). (A two-dimensional face cut parallel to a cozonal lineation defined by tabular feldspars (see Figure 3.1C would also yield the same exposure, but a horizontally oriented cozonal lineation was never detected in the field). The foliation plane can be observed in exposures that reveal the largest crystal faces of feldspar megacrysts (plane xy on Figure 4.2A and B; Plate 4.1B and Plate 3.1B). These exposures are common in the high feldspar content varieties of biotite pyroxene syenite (BPS).

While foliation fabrics defined by feldspar SPOs are highly developed in most of the facies found within the SIC, the degree of alignment of megacrysts within a foliation fabric can range from weak (Plate 4.1C), to strong (very well developed) (Plate 4.6B). Some fabrics can include a few scattered grains that are oblique to an otherwise well-developed foliation (Plate 3.2B). Field descriptions of the degree of alignment within a foliation fabric are quantified in Appendix A3. While some of the strongest foliation fabrics occur in rocks with up to 75% modal feldspar megacrysts, this is not a fixed rule.
Examples of very strong parallel alignment of grains can be seen where the megacrysts appear to be freely floating in matrix (Plate 4.6B), as well as in grain-to-grain contact (Plate 4.2A). Variations in the degree of SPO development can occur on a single compositionally homogeneous outcrop.

While foliation fabric orientations are fairly constant on an outcrop scale and within individual tabular bodies, those bodies are numerous, each exhibiting its own foliation orientation (Map 1.1). Thus foliation orientations for the SIC are widely distributed, but there are strong peaks oriented around 115° and 165° (Figure 4.3). Most foliation fabrics in the SIC have steep to vertical dips.

**SPO-Defined Lineations**

Two types of SPO lineations occur in the SIC:

1. Lineations defined by tabular crystals with a common zone axis (Figure 3.1C).
2. Lineations defined by the shape-preferred orientation of the long dimensions of elongate particles (Figure 3.1A).

Lineations in the first category are common throughout the SIC. In horizontal exposures where the feldspars that define a foliation are only subparallel, vertical exposures of the same rock indicate that all of the feldspars possess similar dips, thus defining a cozonal intersection lineation (Figure 3.1C). These cozonal lineations are generally steeply inclined to vertical, and occur as part of most of the SPO-defined foliations in the SIC.

Lineations in the second category, or those defined by linear preferred orientations of the long axes of rod-shaped biaxial particles, or the long axes of triaxial particles, occur throughout the SIC. Rod shaped biaxial particles includes prismatic feldspars, pyroxenes and amphiboles, while triaxial grains are limited to lathlike or tabular feldspar grains. All occurrences of measurable lineations in the SIC are steeply plunging or vertical (Map 1.1).

The following are examples of lineations from this second category specific to various facies found within the SIC.

**Lineations in Amphibole-Rich Syenites**

Several occurrences of amphibole rich syenite (BAS and AQS) contain a lineation defined by the shape preferred orientation of matrix amphibole grains. Most of these
rocks contain a very well developed foliation defined by tabular feldspar grains (Plate 3.8A), and close examination of hand samples reveals the amphibole lineation as a moderate to strong preferred orientation of amphiboles lying in the feldspar foliation plane. This lineation is easily detectable in orthogonal thin section pairs. In sections taken roughly parallel to the lineation the majority of amphibole grains are elongate with their c-axis lying in the plane of the section. Thin sections perpendicular to the lineation show amphiboles cut perpendicular to their c-axis (Plate 3.6B). This same phenomenon is seen in hand samples whose faces are parallel (Plate 4.2C) and perpendicular to the lineation axis (Plate 4.2D).

**Lineation in ‘prismatic’ BPS**

While most of the syenite facies in the SIC contain tabular feldspar megacrysts, there are several occurrences of a variety of biotite pyroxene syenites (BPS) containing euhedral, unbroken feldspars with pronounced prismatic forms (see Chapter III). A typical aspect ratio for one of these grains is 1.0:1.3:5.3, similar to that of an amphibole grain. The megacrysts are typically 15-20 mm long, and can be floating in a fine-grained matrix or tightly packed together in grain to grain contact. Inspection of favourable exposures reveals horizontal outcrop surfaces with the majority of feldspars cut perpendicular to their long axes, and adjacent vertical rock faces exposing the long axes of feldspars, thus defining a very well developed lineation (Plate 4.3A and B). This observation is confirmed in orthogonal cuts of hand samples and in thin section pairs (Plate 3.5A).

**Lineations in foliation planes**

Most of the feldspar megacrysts in the SIC are triaxial tabular particles exhibiting a typical aspect ratio of 1:4:7. While many of the rocks containing these feldspars exhibit a foliation, it is difficult to determine the exact orientation of the long axes of the feldspars within the foliation planes (Figure 4.2). A foliation is clearly defined by the parallel arrangement of elongate sections through the feldspars, but the similarity in length of the two longer axes presents difficulties in determining whether one is viewing the long section, the intermediate section, or an oblique section (Figure 4.2A and B). In the varieties of syenite where very coarse feldspars form more than 60% of the mode (BPS), several outcrops provide the correct exposure geometry for the detection of a lineation within a foliation plane. This lineation is defined by the preferred orientation of the long
axes of tabular feldspars within a planar preferred orientation or foliation (Figure 4.2B; Plate 4.3C and D).

Other SPOs
In the SIC, most of the foliations and lineations defined by the preferred orientation of megacrysts are well developed and continuous on an outcrop scale. But there are variations in the intensity of these fabrics that occur between adjacent outcrops of similar material, as well as on a single outcrop. Local disturbances or variations of typical fabrics can also be observed. Some outcrops exhibit local folds, shears, and kinks in otherwise well foliated material (Plate 4.4A and B), and individual outcrops can yield different fabrics within several square metres of exposure. One of these outcrops exhibits:

1. domains with well developed foliations (Plate 4.4D),
2. domains with poorly developed foliations (Plate 4.5A),
3. localised shears at a high angle to the trace of foliation (Plate 4.4D),
4. enclave-rich domains with deflection of foliations (see below), and
5. a discordant tube or dike at a high angle to the dominant foliation trajectory (Plate 4.5B and C).

In two facies types, the GAS and BPS, significant amounts of mafic-rich enclaves occur. In the GAS, these enclaves can account for up to 15% of the rock exposed and are up to 20 cm long. These enclaves appear to be discrete units that were transported along with the bulk of the GAS magma, and were therefore partially cooled during transport (see Chapter III). In hand sample and thin section the contacts between enclaves and their host rock exhibit evidence of plastic behaviour of the enclaves (Plate 3.8B and D). While randomly oriented in some exposures, GAS enclaves typically exhibit a preferred orientation of their sectional long axes, whose trend is coincident with the trace of the feldspar foliation in the same outcrop. In some cases, the feldspars in the surrounding matrix often define a foliation which 'bends' around the enclave, yielding a minor and very localised deflection or disturbance in an otherwise well developed foliation. Exposures containing xenoliths of the host volcanic rocks exhibit similar localised deflections of foliation fabrics. In one example, the foliation is deflected around one end of the xenolith, and terminates against the opposite side (Plate 4.4C).
circular arrangement of feldspar megacrysts was observed in the SIC. The feldspar grains are packed tightly together in a series of nested circles highlighted by several concentric, mafic-rich circles (Plate 4.5D). Similar circular patterns of feldspar grains are observed in the syenite/trachyte dikes found in the surrounding volcanic rocks; these will be presented in a later section to follow. The majority of the variations in fabrics or unusual patterns found in the SIC are characterised by vertically or near vertically dipping feldspars.

**Fabrics and Contacts**

Contacts between mineralogically similar intrusions are often defined by differences in shape preferred orientations of crystals. Tabular bodies of rocks generally exhibit feldspar fabrics in which the preferred orientations are parallel to the margins of the body. In exposures of multiple intrusions, especially successively sheeted parallel bodies, the feldspar foliations are commonly the same orientation (same trend) as intrusion contacts (Map 1.3). Examples of feldspars that are not parallel to a margin occur where the rock has been cut discordantly by a later intrusion (Plate 3.1C and D; Plate 4.5C). This yields a contact that is a truncation margin with respect to the older rock, and a primary margin for the younger rock.

**SYENITE/TRACHYTE PORPHYRY DIKES**

**Fabrics in Dikes**

At the Aldermac Mine site the volcanic rocks and the SIC are host to a number of porphyritic and megacrystic dikes. These dikes are generally porphyritic trachytes and megacrystic syenites, with minor amounts of porphyritic rhyolites. Most of these are characterised by low to moderate concentrations of particles (such as feldspar megacrysts and larger mafic minerals including pyroxenes and/or amphiboles) exhibiting strong shape preferred orientations (SPO).

The earlier and numerically dominant dike facies (BAD, BPD, AQD) exhibit a wide range of macroscopic fabrics defined by these SPOs, visible in outcrops with two and three-dimensional exposures. These fabrics range from no discernible preferred
orientation of feldspars to very well developed SPO defined foliations, lineations and other unusual arrangements of megacrysts.

**SPO-Defined Lineations**

A lineation defined by the long axes of biaxial mineral grains is detectable in one rock type, the QFD facies. The long axes of euhedral doubly-terminated quartz grains, in a quartz-feldspar porphyry dike, trace a lineation of unknown orientation (assumed to be margin parallel). A lineations defined by the long axes of triaxial mineral grains (as seen in the SIC) is not easily detectable in any of the dikes, although it is likely that it is present in some of the foliated rocks.

**SPO-Defined Foliations and Related Fabrics**

While examples of dikes with no visually discernible SPO of megacrysts exist (Plate 4.6A), the most common SPO consists of a parallel arrangement of feldspar megacrysts, defined, in outcrop by the parallel arrangement of the trace of their long sections (foliation trace) (Plate 4.6B). Outcrops that allow for examination of a three dimensional exposure, (e.g. two mutually perpendicular exposures are usually sufficient), confirm that the tabular feldspars share a plane parallel arrangement. This foliation plane is usually parallel to the margins of the dike, i.e. contacts with the host rock (Plate 4.6B), but other fabrics and orientations are also observed. Varieties of fabrics or arrangements of megacrysts found within the dikes can include:

1. Well-developed margin parallel SPOs at the margins of a dike with apparently random fabrics in the interior.
2. Concentrations of feldspars with their long axes oriented perpendicular to dike margins (usually found touching a dike margin) (Plate 4.6C).
3. ‘Tiling’ (Den Tex, 1969) of megacrysts at dike margins (Plates 4.7A and B; Plate 4.6C).
4. Jogs in dike margins with randomly oriented feldspars in their apices, and foliations that appear to bypass these apices (Figure 4.4B).
5. Jogs in dike margins with foliations abutting the terminus of an offset (Plate 4.7C and D).
6. Jogs in dike margins with foliations that match the curvature of the offset (Figure 4.4A).

7. SPO-defined foliation in apophyses.

8. Circular arrangements of tabular feldspar grains.

Most of the SPOs in syenitic dikes are defined by feldspar megacrysts suspended in a fine-grained to aphanitic matrix. Grain-to-grain interactions are rare and are usually limited to 'tiling', rafts, or 'log jams' of feldspar grains generally found located near dike margins (Plates 4.7A and B).

A striking feature that can be found in some of the dikes is a circular arrangement of feldspar grains (Plate 4.8A, B and C). These circles are limited in occurrence to dikes of the BPD facies and are defined by feldspars whose long sections are tangent to a set of concentric circles. The true orientations of the long axes of the feldspars are not known. Modal feldspar concentrations vary in some dikes containing circles, with a high 50-60% feldspar content within the circles, and low 10-30% feldspar concentration in adjacent or circle free areas (Plate 4.8D). The outside diameter of a circle is typically limited by the width of the dike that contains it, but some examples may have their outer circles 'truncated' by the dike margins (Plate 4.8B). Circles are often found in multiples of two or three, located side by side, with randomly oriented grains occupying the vertex defined by two circles and a dike wall (Plate 4.9A). The feldspar may also define a series of concentric ellipses (Plates 4.9B and C); with the long axis of the ellipse parallel to the host dikes strike length (this may also be a section effect of the exposure). The centre of some of these elliptical SPOs may contain randomly oriented feldspars, or feldspars whose orientations do not conform to the dominant circular SPO (Plates 4.9B and C).

Dikes containing circles may exhibit irregular contacts with their host rocks. This phenomenon is common in the dikes on the Mill Hill Outcrop (Map 1.2) but it is not seen in dikes containing circles in other parts of the map area.

**DISCUSSION**

Given the tabular morphology of most of the individual igneous bodies that make up the SIC, and its numerous related dikes, models for magma flow, flow indicators and the acquisition of SPO fabrics in dikes should provide a useful starting point for the
interpretation of the Aldermac intrusive rocks. Current models invoking Jeffery-style rotation of non-interfering grains, in a viscous medium undergoing two-dimensional planar flow of magma by simple shear (between two parallel rigid boundaries) are insufficient to explain the fabrics and modal percent megacryst contents found in many of the rocks at Aldermac. It is likely that the feldspar SPOs are not all entirely related to the strain-field associated with their initial intrusion and transport. Rather, through this SPO, the rocks preserve the record of a combination of transport to their current locale and of later, in situ fractionation.

SPO Fabrics in the Aldermac Intrusive Rocks
Within the SIC, there is a wide range of feldspar megacryst content and in the strength of shape-preferred orientations. Megacryst content is usually high, yielding fabrics defined by megacrysts in grain-to-grain contact. Foliations are usually parallel to intrusive margins, collectively yielding a wide range of orientations at map scale. Rather than being associated with some broad diapiric ascent of the Aldermac syenite, the patchwork of local fabrics record its progressive emplacement as many, variably oriented vertical sheets. The SPO within each sheet is related to its magmatic emplacement strain and later filter pressing.

Fabrics in the dikes found both in and around the SIC exhibit similar variations in degree of development but are usually found in rocks with lower feldspar megacryst contents. Many of the dikes are characterised by feldspar megacrystals floating in matrix. Grain to grain contact of megacrysts is usually limited to isolated occurrences of tiling and logjams in otherwise low megacryst content dikes.

Simple Shear Flow Models of SPO Fabric Acquisition
A preferred orientation of inequidimensional markers suspended within a flowing matrix will only develop where a velocity gradient exists, such as near the walls of a dike. Current models for the development of SPOs in simple shear flow of magma rely on the relations of Jeffery (1922). These assume that particles are suspended in a matrix, i.e. there must be no particle-to-particle interactions (collisions). Physical modelling indicates that, at any instant, there is a weak preferred orientation due to the relative rates of
rotation of particles dictated by their orientation with respect to the flow axis. This model does not account for highly developed fabrics commonly seen in syenites and other porphyries with elongate markers. Nor does the model account for rocks with higher marker content (i.e. a megacryst content where interference of grains would occur during rotation). Modelling indicates that there is a decrease in the degree of development of SPOs with an increase in particle content (Ildefonse and Fernandez, 1988). While examples of rocks in the SIC containing megacrysts suspended in matrix exist, these are outnumbered by examples with greater than 20% megacrysts, a fraction which, for this crystal aspect ratio, would lead to significant grain interaction. Regardless, both can, and often do contain highly developed SPO fabrics, which are not predicted by this model. It must also be considered that the above model is constructed to look at the degree of fabric development at any instant. It does not account for the cooling processes in real rocks.

**Proposed Model of SPO Acquisition: Freezing-Wall Accretion**

In classic ‘tiling’, as defined by Den Tex (1969), the wall rock interferes with the rotation of megacrysts (i.e. acts as a ‘rotation inhibitor’) yielding an imbricate stack of megacrysts (Figure 4.1A). The acute angle between the long axis of the crystals and the dike margins opens in the direction of flow, yielding a useful flow direction indicator (Den Tex, 1969; Philpotts and Asher, 1994). Rationalisation of well-defined planar SPOs parallel to dike margins assumes the same presence of a rotation inhibitor – the solidifying magma itself. In a dike, the solidification of magma does not occur simultaneously in all parts of the flow. Rather, a solidification front moves incrementally from the margins towards the centre of the flow (Philpotts and Asher, 1994). This would result in different viscosities and therefore different rheologic conditions ranging from semi solid state behaviour near the margins and still viscous suspension behaviour in the middle, possibly with some finite boundary condition separating the two regimes. In this model, magma flowing along the margin of a sheet cools and solidifies first, thus providing a sticky surface that captures megacrysts that are tumbling or sliding along within the continuing magma flow. Those megacrysts rotating near the ‘sticky’ dike wall would be caught and prevented from rotating beyond a margin parallel orientation, while those sliding would
simply be captured by the viscous frozen margin. Thus the wall would act as a rotation inhibitor and a plane of accumulation of frozen magma. Minerals other than the feldspars are also likely to be captured in the same manner. The process continues as the cooling proceeds inward and the thickness of the frozen margin increases. This phenomenon is defined here as ‘freezing-wall accretion’.

A similar mechanism can be observed by watching elongate pieces of ice floating down a river. Those travelling in the interior of the river rotate freely and/or continue to glide down the river, while those markers travelling near the banks of the river will rotate until an end of the marker contacts other pieces of ice accumulated along the banks or still attached to the bank. This marker will rotate around its point of contact (end of marker) with the bank and then stick to the riverbank in a metastable, margin parallel position. This freezing-wall accretion model can be used to explain tiling, where imbricate stacks of megacrysts form against the dike margin. Diagrams illustrating this phenomenon usually show one feldspar parallel to the wall with an imbricate stack leaning against it, similar to the pattern resulting from several thick books falling over on a bookshelf.

*Application of the Freezing-Wall Accretion Model at Aldermac*

The freezing-wall accretion model works well for magmas with lower than 50% modal feldspar, as it requires that some of the grains which are being captured by the sticky wall material are still able to rotate into a margin parallel position, unimpeded by other grains still in the magma. Several examples of dikes found at Aldermac exhibit strong feldspar SPOs defined by freely floating grains near the dike margins, and well developed but isolated tiling directly adjacent to contacts. The interiors of many of these dikes have poorly developed SPOs (or apparently random megacryst fabrics). These dikes fit the freezing-wall accretion model fairly well. But is it possible that this mechanism could account for very well foliated rocks with up to 70% feldspar? As noted above, most instances of tiling are usually cited as small isolated occurrence in otherwise low megacryst mode dikes (Plate 4.7A). But these individual tiled patches possess very high feldspar modes. The freezing-wall accretion mechanism could allow a 30% mode feldspar magma to fractionate by accumulating megacryst at the walls while the matrix
material continued to flow and escape the igneous body. This could result in a very high modal megacryst rock with a strong SPO. It is apparent that the matrix is not necessary to form the sticky material that might catch a megacryst, as there is ample evidence in the BPS, and BAS facies rocks in the SIC that the feldspars continued to crystallise after they became stationary. Thus they could have provided their own catching surfaces. Perhaps the greatest weakness in the application of any of these models to the rocks which comprise the bulk of the SIC, is the size of some of the tabular bodies. As stated above these models require a velocity gradient near a dike margin. The acquisition of a strong fabric in some of the SIC exposures would require this idealised incremental solidification to occur consistently over tabular body thicknesses of up to 100 metres (measured), right into the centre of the body.

**Alternative Models of SPO Fabric Acquisition at Aldermac**

Marsh (1981) found that the upper limit of rigid particle content for flow in basaltic lava is 55-60%; although some authors report flow of slurries with crystal content near 90% (A.R. Cruden, *Pers. Comm.*, 1998). Following the assumption that all of the feldspar megacrysts (in the rocks of the SIC) were present at the time of transport, and given the possibility that many of these magmas also contained previously crystallised mafic minerals, it is difficult to rationalise the transport of a magma with 60% feldspar megacrysts or higher. The possibility that megacrysts could have been significantly smaller at the time of transport, and grown to their present size after emplacement can be precluded by the lack of impinging crystal forms (this excludes the minor albite rims described in Chapter III). The spatially repeated occurrence of very high megacryst content rocks in the SIC suggest that many of the magmas have undergone some form of compaction or filter pressing to get such high modes. By filter pressing we mean the escape of a liquid component of a magma from its solid crystal component. There is a lack of sedimentary features such as load structures, scour and fill structures, and graded bedding, which are often associated with the proposed mechanisms of formation of layered intrusions (compaction by gravity similar to the phenomenon which occurs in wet sediments). But evidence for concentration of feldspar megacrysts by a mechanism of filter pressing is dominated by the heterogeneities in the SIC (i.e. variability in
mineralogical modes) seen at all scales (recall Chapter III). Further evidence includes bent grains, folds, kinks, and other irregularities in foliation fabrics, and the presence of groundmass and outcrop scale shears and buckle folds. The outcrop scale shears are observed disturbing the local foliation fabrics and exhibit evidence of having occurred during viscous flow regime i.e. the megacrysts are not broken or plastically deformed in these shears. It appears that any filter pressing that took place at Aldermac was likely a result of space problems associated with the intrusion of the magma into its current location. Mechanisms directly responsible for the filter pressing of the magma (once transported to its current location), might include pressures on an *in situ* body of magma caused by adjacent multiple intrusions.

*Proposed Model of SPO Acquisition in the SIC: Filter Pressing*

If we accept that the rocks at Aldermac have high modal megacrysts as a result of an *in situ* filter pressing of the magma, we must consider how this would affect the types of SPO fabrics found in these rocks. For an ideal model of pure shear we expect a stronger planar preferred arrangement of tabular crystals. The longest axes of both biaxial and triaxial particles (actually the plane defined by the longest and the intermediate axes) will orient themselves perpendicular to the shortening direction. An important observation in rocks of the SIC is the presence of strong lineation found within the foliation planes defined by elongate particles. In one case, this foliation is defined by matrix amphiboles, while another rock type contains a lineation defined by the longest axes of the megacrysts forming the foliation. Ideal pure shear flattening (escape of material in all directions in the flattening plane) does not account for this type of fabric. A more in depth explanation of the evolution of the SIC magmas is required to rationalise these fabrics.

The evolution of the fabrics in most of the rocks of the SIC are considered here in three stages, beginning with the initial bulk transport of a mixed solid-liquid magma to the current exposure level and ending with final crystallisation of the remaining melt.

**Stage one:** Magmas with lower amounts of modal megacrysts (e.g. 20%) may have undergone bulk transport to their current locale (a tabular body in the SIC) via simple shear flow with free, 'Jeffery-style' rotation of megacrysts in the centre of the body. The
magma might contain the very weak preferred orientation predicted by the simple shear flow model. Tiling, as described above, may also be present at the margins of the body, as significant cooling of the magma has not yet occurred. A coaxial strain acting perpendicular to the walls of the tabular body (i.e. wall rock strain) would yield a pure shearing of the magma. This would yield a combination of pure shear compression and simple shear flow of the magma as it escapes in a single direction (upwards, in the SIC).

At this stage in the evolution of the magma and its fabric, rotation of megacrysts is best approximated by a combination of Jeffery rotation, and March rotation (the latter in response to the shortening of the width of the body). This combination of rotation mechanisms is the best candidate for the formation of a lineation of megacrysts and is explained below.

Stage two: The viscosity contrast between the megacrysts and the matrix liquid would cause a continuous decrease in the ratio of liquid to solids as melt becomes decoupled from the megacrysts and escapes the igneous body. This would result in an increase in megacryst content. There is a dramatic increase in rotation rates as grain to grain interactions become more prevalent. The fabric already developed at this point, a pure shear foliation – and the matrix driven lineation, would be intensified by the interaction of the feldspar grains. The pure shear would drive the megacrysts into a planar preferred orientation, while a matrix-shear driven linear preferred orientation of the megacrysts would become stronger and form in a mechanism similar to that of tiling, where neighbouring megacrysts act as sticky rotation inhibitors. At the point when megacrysts begin to interact they would provide an infinite set of rotation inhibitors throughout the thickness of the body.

Stage three: Upon grain to grain interaction a critical point would be reached where the feldspars no longer translated along the body but may still have continued to rotate in place. At this stage little liquid remains to be expelled from the mush. Eventually megacrysts are bound on all side by other megacrysts and/or solidified matrix. Rotation of megacrysts is limited to the intensification of the planar preferred orientation (foliation) in response to continued pure shear strain.
In the SIC the vertical orientation of the lineations defined by the long axes of mafic matrix grains is thought to represent the escape direction of the remaining liquid upwards and away from the crystals. The presence of shears in the groundmass in some of these rocks is consistent with the work of Smith et al. (1993) where conjugate shear sets in basaltic dikes are considered to be a result of a minimum of 15% shortening of the dike perpendicular to its margins. Larger outcrop scale shears that disturb the foliation fabrics in some SIC outcrops may also result from the shortening of those bodies. Large folds and other irregularities point to a less than ideal flow regime in the SIC. The presence of folded foliations in isolated material suggests that flow may have occurred in isolated pathways as the rocks progressively cooled, i.e. previously compacted, megacryst-rich rock was remobilised (from the dike walls) and retransported along the still open pathways in the dike. Transport along isolate pathways (within already consolidated rock) appears to have happened where circular arrangements of feldspar occur in otherwise well foliated material of the same composition. The ‘tube’ found in one of the outcrops might also represent a similar phenomenon. Foliation fabrics that deflect around xenoliths and mafic enclaves also suggest that some degree of the fabric was formed by a pure shear mechanism.

Proposed Model of SPO Acquisition in the Alderman Dikes: Filter Pressing

It is important to note that the above model need not be confined to rocks with very high megacryst modes. It was noted in Chapter III that some of the matrix grains may have already crystallised in a subjacent magma chamber prior to bulk transport to the level of the pluton. These grains, combined with others that would continue to crystallise as the magma cooled, would provide the freezing-wall accretion mechanism (when attached to megacrysts) required for fabric formation. Thus the same mechanism that formed the strong SPO foliations in the SIC may also have been active in the dikes. Although it has been suggested that many of the dikes at Alderman could have acquired their SPO fabrics by the freezing-wall accretion model under simple shear conditions, other dikes at Alderman possess SPOs and fabrics that clearly do not result from this idealised flow regime. The best evidence for this lies in the circles found in many of the dike's found
intruded into the volcanic rocks south of the SIC. These circles probably represent a maturation of the transport regime over the cooling history of the dike. At some point in the history of the dike the bulk transport flow appears to have evolved to a state where transport of magma may have been confined to feeder tubes whose outside diameter started equal to the dike width. Concentrations of megacrysts in grain to grain contact within these circles may be attributed to a progressive constriction of the conduit as the megacrysts became stuck to the walls during cooling (the ‘sticky’ rotation inhibitor effect). These high concentrations contrast with the lower modal amounts of feldspars found in adjacent portions of many of these dikes. The centres of these circles lie in the centre of their host dikes, suggesting an equal distribution of forces (whether responsible for the magma movement or not) on either side of the dike. The orientation of the circles suggests a magma transport direction in the current vertical.

**SUMMARY**

The SPO fabrics found in the intrusive rocks at the Alderma Mine site are related to the processes that have affected each individual body. The fabrics do not represent an overall strain field imposed during the emplacement of the body as a simple diapir. The current models for the acquisition of igneous SPO fabrics are not applicable to many of these rocks. A model for bulk transport flow of magma and Jeffery rotation must be modified by the introduction of the concepts of a rotation inhibitor and freezing-wall accretion to account for the highly developed SPO fabrics found in many of the lower feldspar content rocks. Those rocks with higher feldspar contents require a new model combining three phases in the transport of a magma, including:

1. A combination of simple shear and pure shear flow with low megacryst content allowing escape of the magma (including megacrysts) as the body deflates.

2. An intermediate pure shear/simple shear stage, involving decoupling of the liquid matrix from the trapped megacrysts.

3. A final stage involving pure shear filter pressing of the magma – causing fractionation and intensification of SPO fabrics
Table 4.1. Classification of fabric intensity for SPO foliations in the Aldermac Mine area.

<table>
<thead>
<tr>
<th>Descriptive Intensity</th>
<th>Numerical Classification</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random (apparent)</td>
<td>[0]</td>
<td>Plate 4.6A</td>
</tr>
<tr>
<td>Very weak</td>
<td>[1]</td>
<td>Plate 4.1C</td>
</tr>
<tr>
<td>Poorly developed</td>
<td>[2]</td>
<td>Plate 4.7A</td>
</tr>
<tr>
<td>Moderate</td>
<td>[3]</td>
<td>Plate 4.1D</td>
</tr>
<tr>
<td>Well developed</td>
<td>[4]</td>
<td>Plate 4.1A</td>
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<tr>
<td>Very well developed</td>
<td>[5]</td>
<td>Plate 4.6B</td>
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Figure 4.1. Textures and fabrics found in dikes, which are commonly interpreted as flow direction indicators: (a) imbricate or tiled phenocrysts (SPO fabric); (b) broken and sheared phenocrysts (texture); (c) mafic or felsic wisps emanating from wall rock (texture); (d) segregations on opposing corners of phenocrysts (texture); (e) groundmass shear ('Riedel') zones (texture); (f) ramp structures formed by phenocrysts (fabric). Figure redrawn from Philpotts and Asher, (1994).
Figure 4.2. Diagrammatic representation of idealised lineations (L) and foliations, illustrating the relevance of exposure and viewpoint. 

(A) A combination of a foliation defined by the shape preferred orientations of tabular grains, and a lineation within the foliation plane, defined by the long axes of the triaxial tabular grains. Note that observation of the xz and/or yz plane(s) reveals a lineation, which is the trace of the foliation, but does not give a reliable indication that a lineation within the foliation plane is present. Study of the exposed xy plane reveals a preferred orientation or lineation defined by the longest axes of the triaxial grains. (B) A well-developed foliation defined by the shape-preferred orientations of tabular grains. Note again that observation of the xz and/or yz plane(s) does not reveal any information about the alignment of grains within the foliation plane [Note the similarity of the respective xz and yz planes between (A) and (B)]. The exposed xy plane in this case reveals that the long axes of the triaxial grains are randomly oriented within the foliation plane.
Figure 4.3. Frequency rose diagrams for the orientation of SPO foliations found within the Syenite Igneous Complex (SIC).
(A) SPO foliations found within the SIC (includes all facies with detectable foliations).
(B) SPO foliations found in the voluminously significant biotite pyroxene syenite (BPS), which forms most of the SIC.
(C) SPO foliations found in the remaining facies types found in the SIC.
All values are unweighted.
Figure 4.4. Variations in margin parallel shape preferred orientation within syenite/trachyte dikes. (A) A well-developed margin parallel SPO defined by feldspar megacrysts bends and matches the curvature of a jog in the margin of a dike. (B) A phenomenon similar to that found in (A), in a dike with a slightly sharper (orthogonal) jog. The apex or orthogonal portion of the jog contains randomly oriented feldspars, while the rest of the foliation planes gently curve around the jog. Diagrams are of horizontal outcrop exposures. The size of the feldspar grains has been slightly exaggerated for simplicity. A dike with these types of features has a typical width of 60-70cm.
Plate 4.1. Syenite Intrusive Complex: foliations.

(A) Outcrop exposure of a well-developed [1] foliation in a very coarse grained biotite pyroxene syenite (BPS). The mafic matrix weathers out leaving feldspars exhibiting portions of all three crystal faces (the largest crystal faces are highlighted by shadows). Photograph is of a horizontal surface; Brunton transit lid is 70mm wide. Location: outcrop 8/24-7.

(B) Outcrop exposure of the foliation plane of a biotite pyroxene syenite (BPS). This unusual exposure reveals the large faces of tabular feldspar megacrysts, roughly lying within a foliation plane. Visible on the crystal faces are partially enclosed pyroxene grains or their casts. The megacryst on the bottom right is an inversion twin. Photograph is of a vertical surface; coin diameter is 21mm. Location: outcrop 7/19-1.

(C) Outcrop exposure of a pyroxene amphibole syenite (PAS) with a very weak [1] orientation of feldspar megacrysts (foliation parallel to the height of the photograph). Coin diameter is 21mm. Photograph is of a horizontal surface. Location: outcrop 7/9-10.

(D) Outcrop exposure of a moderate [3] foliation in a BPS. Note the absence of feldspar grains exhibiting their large tabular faces. This rock contains examples of bent grains (b), and grains whose orientation is oblique to the main foliation (o). Photograph is of a horizontal surface; lens cap diameter is 55mm. Location: outcrop 7/19-1.
Plate 4.2. Syenite Intrusive Complex: foliations and lineations.

(A) Outcrop exposure of a very well-developed foliation [5] in a very coarse grained biotite pyroxene syenite (BPS). Photograph is of a horizontal surface; field of view is approximately 1m wide. Location: outcrop 8/24-10.

(B) Outcrop exposure of a well-developed foliation [4] in a pyroxene amphibole syenite (PAS). The trace of the foliation runs across the width of field, in this photograph of a horizontal surface. Arrows indicate feldspars that are oblique (orthogonal) to the main foliation. A small aplitic AQD cuts the lower left corner of the image. Coin diameter is 21mm. Location: outcrop 7/9-1.

(C) Photograph of a well-developed lineation in an amphibole quartz syenite (AQS). The majority of the amphiboles are lying in the plane of the photograph (the feldspar foliation plane is not visible). The purple increments on the scale are 1cm long. Sample 6/25-5/2.

(D) Photograph of a well-developed lineation in an amphibole quartz syenite (AQS). This photograph is of an orthogonal cut to the face seen in (C). The majority of the amphiboles (concentrated in the white-coloured, weathered rind) are cut perpendicular to their long axes (arrow: a). Note the euhedral quartz phenocrysts (arrow: q). The feldspars define a foliation parallel to the width of the photograph. Width of field is approximately 35 mm. Sample 6/25-5/2.
Plate 4.3. Syenite Intrusive Complex: foliations and lineations continued.

(A) Outcrop exposure of a foliated and lineated biotite pyroxene syenite (BPS). This photograph is of a horizontal surface, which is itself a perpendicular cut of an SPO defined lineation and foliation. The feldspar megacrysts in this rock possess a nearly prismatic habit, and their long axes are preferentially oriented in the current vertical. Arrows point to rare grains that are oblique (orthogonal?) to this lineation, yielding sections parallel to their long axes. The foliation plane is defined by the trace of the intermediate axis of the feldspars (in this photograph the foliation is indicated by the transit, and is highlighted by the preferred orientation of the spurious long sections). Some examples of this rock type only contain a detectable lineation. Brunton transit lid is 70 mm wide. Location: outcrop 8/28-5.

(B) Outcrop exposure of lineated biotite pyroxene syenite (BPS). Oblique photograph shows horizontal surface in the foreground similar to that found in Plate CF8-36, and ruler resting against a raised vertical surface. This vertical surface contains abundant sections of prismatic feldspar megacrysts cut parallel to their long dimensions (arrows). Top of ruler is marked in centimetres and millimetres. Location: outcrop 8/28-5.

(C) Photograph of a sample with good exposure of the SPO foliation plane, in a rock with a very well developed foliation. The large tabular faces of feldspar megacrysts are clearly visible, and their long axes have a preferred orientation (lineation within the foliation plane). Outline on lower left grain shows original shape of grain, which was broken during collection. The original orientation of this face was vertical with the lineation plunging vertically. Sample 8/30-1/2.

(D) Photograph of another sample with good exposure of the SPO foliation plane, in a rock with a very well developed foliation. The large tabular faces of feldspar megacrysts have a preferred orientation (lineation within the foliation plane). The outline on the upper left grain, which was broken during collection, shows its original shape. The original orientation of this face was vertical with the lineation plunging vertically. The scale is marked in centimetres (major units). Sample 8/21-5/1.
Plate 4.4. Syenite Intrusive Complex: variations of fabrics.

(A) Outcrop exposure of a fold in well-foliated [4] BPS. Brunton transit is parallel to the trace of the main foliation in the outcrop. The arrow marks a truncation of the dominant foliation by the fold surface. Photograph is of a horizontal surface, and all feldspars, including those in fold, dip approximately 90°. Brunton lid is 70mm wide. Location: outcrop 8/24-10.

(B) Outcrop exposure of an unusual kink fold within a mafic rich enclave of BPS. Photograph is of a horizontal surface. The kink folded area is in the centre of the image, and possesses a fairly high modal content of feldspar megacrysts. The arrow indicates a feldspar poor region of the enclave. Ruler is approximately 16cm long. Location: outcrop 7/19-1.

(C) Outcrop exposure of a volcanic xenolith in BPS. Euhedral feldspars closely packed together define the trace of a well-developed foliation [4] running from top to bottom of photograph. Foliation is deflected around bottom edge of xenolith but appears to be truncated at top edge. Photograph is of a horizontal surface; Brunton lid is 70mm wide. Location: outcrop 8/24-4.

(D) Outcrop exposure of a very well developed foliation [5] in a BPS. A shear (arrow) disturbs the foliation across the width of the photograph. The photograph is of a horizontal surface and the foliation is vertical. Width of field is approximately 55cm. Location: outcrop 6/15-2.
Plate 4.5. Syenite Intrusive Complex: variations of fabrics, continued.

(A) Outcrop exposure of the same BPS seen in Plate 4.4 (D). Foliation development in this photograph areally ranges from poor to very good on a decimetre scale. Photograph is of a horizontal surface, and all feldspars dip approximately 90°. Field of view is approximately 115cm wide. Location: outcrop 6/15-2.

(B) Outcrop exposure of a BPS exhibiting several variations of SPOs. Most of the field is dominated by tightly packed feldspar megacrysts defining a well-developed foliation fabric (f). Mafic enclaves (m) are present, and a later discordant dike or tube (t) of the same material as the bulk of the outcrop, runs diagonally across the photograph. Field of view is approximately 1m wide. Photograph is of a horizontal surface. Brunton transit lid is 70mm wide. Location: outcrop 6/15-2.

(C) Outcrop exposure of the tube seen in (B). The relief of the tube in this exposure is raised, with a high point at its centre (similar to a mold of the inside of a pipe). The feldspar megacrysts are unusually elongate (1), and oriented with their long axes parallel to their discordant contacts (2) with the host rock. Note that the host rock is made of the same material, and its feldspar megacrysts have been truncated (3). The feldspar megacrysts in the tube also appear to be arranged with the poles of their large faces oriented towards the (imagined) central axis of the tube (4). Photograph is of a horizontal surface. Ruler is approximately 16cm long. Location: outcrop 6/15-2.

(D) Outcrop exposure of a rare circular arrangement of feldspar megacrysts in a pyroxene amphibole syenite (PAS). Arrow (c) marks the approximate centre of the circular feature. The curved folia are easier to see on the right side of the image (1), but the series of concentric circles is also highlighted by curved mafic rich zones (2). The photograph is of a gently curving horizontal surface. Coin is 21mm in diameter. Location: outcrop 7/9-9.

(A) Outcrop exposure of a BPD with an apparent random orientation of feldspar megacrysts [0]. Many of the grains in this image present their largest tabular faces (arrows). This rock is unusual, as it does not contain even the simple lineation defined by a common axis of intersection of tabular grains, which is seen in many of the other examples of syenite. The right hand margin is coincident with a contact with the host rock. Photograph is of a horizontal surface. The width of field is approximately 25cm. Location: Mill Hill; Dike R.

(B) Outcrop exposure of a very well developed [5] foliation in a biotite amphibole dike (BAD). Feldspar megacrysts are typically floating in matrix and form a strong margin parallel foliation. Note the sharp contact with the host volcanics. Photograph is of a horizontal surface. Coin is 21mm in diameter. Location: outcrop 8/4-3.

(C) Outcrop exposure an atypical SPO fabric in a BPD. Feldspars demonstrate a well-developed SPO, but they are oriented perpendicular to the margins of the dike (ruler marks contact). Arrow indicates classic tiling. (Both of these phenomena are probably genetically related). Photograph is of a horizontal surface. Location: outcrop 8/9-1.
Plate 4.7. Syenite/Trachyte Porphyry Dikes: variations in fabrics.

(A) Outcrop exposure of tiled feldspars in a biotite amphibole dike (BAD). The line highlights a minor indentation in the contact between the dike (lower part of photograph) and the host volcanic rock. The indentation contains abundant feldspar megacrysts in face to face contact, and the long axes of these feldspars are all preferentially oriented oblique to the margin of the dike, or tiled (Den Tex; 1969). Megacrysts in the remainder of the dike occur as isolated free-floating grains or small glomerocrysts. Note the zoning and rounding of the feldspar megacrysts (arrow). Photograph is of a horizontal surface. Ruler is marked in centimetres (major units). Location: Mill Hill, dike ‘Harry’.

(B) Outcrop exposure of a poor [2] (near margins) to moderate [3] SPO foliation in a (BAD). This is the same dike shown in photograph (A). Note the tiled feldspars (arrow) shown in photograph (A). Most of the feldspars appear to be isolated in matrix, and define a margin parallel foliation. The white line marks the contact with the host volcanic rocks. Photograph is of a horizontal surface. The mechanical pencil is approximately 15 cm long. Location: Mill Hill, dike ‘Harry’.

(C) Outcrop exposure of a very well-developed margin-parallel foliation [4] in a BPD with a dextral offset. The strike direction of the dike is roughly parallel to the left and right edges of the image (the left margin is marked in white), and volcanics occupy the upper left of the image (v). Inspection of the outcrop suggests that the offset is syndepositional. Feldspar megacrysts are typically floating in matrix, and the well-developed foliation projects straight into the offset (arrow). Note the sharp contact with the host volcanics. Photograph is of a horizontal surface. Width of field is approximately 25cm. Location: outcrop 8/9-1.

(D) Outcrop exposure of a well developed margin-parallel foliation [3] in a BPD with a dextral offset. This phenomenon is the same as that seen in (B). The white line marks the volcanic-dike contact, and pink highlights individual feldspar megacrysts. Photograph is of a horizontal surface. Width of field is approximately 50cm. Location: outcrop 8/9-1.

(A) Outcrop exposure of a well-developed circular arrangement of feldspar phenocrysts in a BPD. The dike margins are coincident with the upper and lower edges of the image. Note the concentration of larger phenocrysts at the centre of the circle (c). Photograph is of a horizontal surface. Ruler is approximately 16 cm long. Location: Mill Hill; dike U.

(B) Oblique photograph of a large biotite amphibole dike with a well-developed circular arrangement of feldspar phenocrysts. The margins of the dike are highlighted in white. Some of the (infinite) nested circles are highlighted for clarity, and the transit lies at their centre. Note that the circular arrangement is truncated at both margins of the dike (arrows). The dike is approximately 2.3 m wide. Location: outcrop 8/21-4.

(C) Outcrop exposure of a well-developed circular arrangement of feldspars in a biotite amphibole dike, as seen in (B). Photograph is of a horizontal surface, and red line indicates a contact with host volcanic rock (arrow). Tabular feldspar phenocrysts constitute approximately 50% of the mode and form an infinite set of nested concentric circles (highlighted). The dike is approximately 2.3 m wide. Brunton transit lid is 70mm wide. Location: outcrop 8/21-4.

(D) Outcrop exposure of a well-developed circular arrangement of feldspars in a BPD. There is a distinctive variation in the modal amounts of feldspar phenocrysts between the circles (1) and the adjacent portions of the dike (2). Note the closely spaced jointing in the volcanics, which does not penetrate the dike (j). Photograph is of a horizontal surface. Ruler is approximately 16 cm long. Location: Mill Hill; dike U.
Plate 4.9. Syenite/Trachyte Porphyry Dikes.

(A) Outcrop exposure of two moderately well-developed circular arrangements of feldspar phenocrysts side by side in a BPD. The dike margins are coincident with the upper and lower edges of the image. The approximate centres of the circles are marked (c). Note the margin parallel feldspars in the interstitial voids created by the circles and the dike walls (arrows). Photograph is of a horizontal surface. Field of view is approximately 1m wide. Location: Mill Hill; dike M.

(B) Outcrop exposure of nested curved folia in a small biotite pyroxene dike (BPD). White lines mark the contacts with the host volcanic rocks, and some of the individual feldspars are highlighted. Folia are mirrored in the portion of dike to the right of the photograph, forming an overall circular arrangement of feldspars, which is truncated by the dike margins. Right side of photograph contains the centre of this circular arrangement (c); note the random orientations of feldspar grains, including exposed tabular faces in the centre of the circle (arrows). Photograph is of a horizontal surface. Ruler for scale. Location: Mill Hill.

(C) Outcrop exposure of a small circular arrangement of feldspars, in a small biotite pyroxene dike (BPD). White lines highlight some of the truncated folia. The centre of the circular SPO lies in the approximate centre of the photograph. Note the random orientations of feldspar grains, including exposed tabular faces in the centre of the circle. Photograph is of a horizontal surface. Ruler for scale. Location: Mill Hill.
CHAPTER V: DISCUSSION AND CONCLUSIONS

COMPOSITIONAL AND MODAL HETEROGENEITY OF THE ALDERMAC INTRUSIVE ROCKS

The Aldermac Mine area is underlain by rocks that may be assigned to three lithologic entities:

1. The Syenite Igneous Complex (SIC).
2. The syenite dikes found within and outside the SIC.
3. The volcanic pile which hosts the SIC and dikes.

The volcanic rocks range from mafic to intermediate in composition. They are heavily silicified, and have undergone subgreenschist metamorphism, with little or no evidence of regional penetrative deformation.

Results of mineralogical, textural, and fabric analyses indicate that there is a definite sequential evolution of the magma that is host to the feldspar megacrysts, and which forms the rocks of the Aldermac SIC and its related dikes. The elongate, roughly north-south trending SIC exhibits a regional scale lithological heterogeneity highlighted by the crosscutting relationships of six syenitic and granitic facies (Table 3.2). These six facies are defined primarily by their matrix mineralogical content and associated textures. Large tabular bodies composed of mafic-rich (biotite-pyroxene) syenite areally dominate the SIC. Abundant syenitic/trachytic dikes have been reported (Gunning, 1927) intruding into the volcanics to the Northwest of the SIC, and are observed radiating around its eastern, southern and western borders, as well as within in its heterogeneous western portion. Some of these dikes are compositionally similar to facies that make up the bulk of the SIC, but they tend to have lower modal amounts of feldspar phenocrysts, aphanitic groundmass minerals, and considerably higher traceable aspect ratios than their larger SIC counterparts. The syenite/trachyte dikes can be divided into five distinctive facies based on mineralogical mode (of the matrix) and associated mineralogical textures (Table 3.5). Spatially repeated crosscutting relationships indicate a temporal relationship between dike facies, ranging from older mafic-rich varieties (BPD and BAD) to the youngest quartz-rich QADs.
Early intrusions of syenite within the SIC exhibit conformable contacts with each other. This can yield multiply-intruded, sheeted parallel bodies of different facies, or sheeted dikes of material of the same facies, varying only in granularity and/or modal amounts of megacrysts. In addition to these map scale heterogeneities (Map 1.1), variations in mineralogical modes can also be observed within an individual outcrop (e.g., 20 m^2), where multiple intrusions of a single facies may differ only in modal fraction of feldspar megacrysts, or variations in matrix mineral proportions. Similar modal variations may also occur at hand sample and thin section scale.

The lithological and modal heterogeneities indicate a fractionation of the magma at all scales. The unique mineralogies and textures of each facies indicates definite, although not understood, initial fractionation processes in one or more underlying magma chambers, prior to transport of magma to the current location. The great variability in modal fractions within each facies indicates that there must have been extensive fractionation between crystals and remaining liquid up to the end of \textit{in situ} crystallisation, yielding significant map, hand, and thin section scale heterogeneities within individual facies.

**ORIGINS OF SHAPE PREFERRED ORIENTATIONS**

Many of the exposures of the SIC and the syenitic dikes exhibit fabrics defined by shape preferred orientations, in the form of lineations, foliations or a combination of both. These are visible in hand sample, thin section and on an outcrop scale. While a lack of extensive metamorphic (recrystallisation and/or penetrative plastic deformation) textures implies that these fabrics are related to igneous transport processes, what stage or stages of transport are preserved, is open to debate.

Many current models for the acquisition of SPOs during simple shear flow of magma (between two parallel rigid boundaries) rely on the relations of Jeffery (1922) rotation. Many of the rocks at Aldermac exhibit modal megacryst fractions that are too high for the free rotation modelled by Jeffery (1922), and SPO that are much stronger than would be expected by free rotation. It is likely that the feldspar SPOs are not all related to the strain field associated with their initial intrusion and transport. Rather, we propose that the SPOs record a combination of transport to their current locale,
progressive inward freezing of the magma within each sheet, and a later in situ expulsion of some remaining melt (fractionation).

**SPO Fabrics in the Alderamac Intrusive Rocks**

Although there is a wide variation of feldspar megacryst content and in the strength of shape-preferred orientations, megacrysts content is usually high, yielding fabrics defined by megacrysts in grain to grain contact. Foliations are usually parallel to intrusive margins, collectively yielding a wide range of orientations at map scale. Rather than being associated with some broad diapiric ascent of the Alderamac syenite, the patchwork of local fabrics record its progressive emplacement as many, variably oriented vertical sheets. The SPO within each individual sheet is related to its magmatic emplacement strain and later filter pressing.

Fabrics in the dikes found both in and around the SIC exhibit similar variations in degree of development but are usually found in rocks with lower feldspar megacryst contents. Many of the dikes are characterised by feldspar megacrysts floating in matrix. Grain to grain contact of megacrysts is usually limited to isolated occurrences of tiling and logjams in otherwise low megacryst content dikes.

**Proposed Model of SPO Acquisition: Freezing-Wall Accretion**

In classic ‘tiling’, as defined by Den Tex (1969), the wall rock interferes with the rotation of megacrysts (i.e. acts as a ‘rotation inhibitor’) yielding an imbriccate stack of megacrysts (Figure 4.1A). In this ‘freezing-wall accretion’ model, magma freezing along the margin of a sheet cools and solidifies first, thus providing a ‘sticky’ surface that captures megacrysts that are tumbling or sliding along within the continuing magma flow. Those megacrysts rotating near the ‘sticky’ dike wall would be caught and prevented from rotating beyond a margin-parallel orientation. Minerals other than the feldspar megacrysts are also likely to be captured in the same way. The process continues inward as cooling proceeds and the thickness of the frozen magma increases.

The freezing-wall accretion model works well for magmas with lower than 50% modal feldspar, as it requires that the grains that are captured by the sticky wall material are still able to rotate into a margin parallel position, unimpeded by other grains still in
the magma. Several examples of dikes found at Aldermac exhibit strong feldspar SPOs defined by freely floating grains near the dike margins, and well developed but isolated tiling directly adjacent to contacts. The interiors of many of these dikes have poorly developed SPOs (or apparently isotropic megacryst fabrics). The freezing-wall accretion mechanism could also allow a 30% mode feldspar magma to fractionate by accumulating megacryst at the walls while the matrix material continued to flow and escape the igneous body. This could result in a very high modal megacryst rock with a strong SPO. It is apparent that the matrix is not necessary to form the sticky material that might catch a megacryst, as there is ample evidence in the BPS, and BAS facies rocks in the SIC that the feldspars continued to crystallise after they became stationary. Thus they could have provided their own ‘sticky’ catching surfaces.

**Proposed Model of SPO Acquisition: Filter Pressing**

The spatially repeated occurrence of very high megacryst content rocks in the SIC suggest that many of the magmas have undergone some form of compaction or filter pressing to get such high modes. If we accept that the rocks at Aldermac have high modal megacrysts as a result of an *in situ* filter pressing of the magma, we must consider how this would affect the types of SPO fabrics found in these rocks. For an ideal model of pure shear we expect a planar preferred arrangement of tabular crystals. The longest axes of both biaxial and triaxial (actually the plane defined by the longest and the intermediate axes) particles will orient themselves perpendicular to the shortening direction. An important observation in rocks of the SIC is the presence of strong lineation found within the foliation planes defined by elongate particles. In one case, this foliation is defined by matrix amphiboles, while another rock type contains a lineation defined by the longest axes of the megacrysts forming the foliation. Ideal pure shear flattening (escape of material in all directions in the flattening plane) does not account for this type of fabric. A more in depth explanation of the evolution of the SIC magmas is required to rationalise these fabrics.

A three-stage model was proposed to account for the SPO in the high megacryst content sheeted bodies (note that the previous model of incremental freezing of the
magma is not precluded in this model, but is left out to simplify the following description):

1. **Stage one**: Magmas with lower amounts of modal megacrysts (e.g. 20%) may have undergone bulk transport to their current locale via simple shear flow with free, ‘Jeffery-style’ rotation of megacrysts in the centre of the body. A coaxial strain acting perpendicular to the walls of the tabular body (i.e. wall rock strain) would yield a pure shearing of the magma. For rocks in the SIC a single escape direction for the expelled magma is likely (upwards?), yielding a combination of pure shear compression and simple shear flow of the magma. At this stage megacrysts would continue to rotate and translate in the escape direction.

2. **Stage two**: The viscosity contrast between the megacrysts and the matrix liquid would cause a continuous decrease in the ratio of liquid to solids as melt becomes decoupled from the megacrysts and escapes the igneous body. The fabric already developed at this point, a pure shear foliation – and the matrix driven lineation, would be intensified by the interaction of the feldspar grains. At the point when megacrysts begin to interact they would provide an infinite set of rotation inhibitors throughout the thickness of the body.

3. **Stage three**: Upon grain to grain interaction a critical point would be reached where the feldspars no longer translated along the body. Eventually megacrysts are bound on all side by other megacrysts and/or solidified matrix. Motion of megacrysts is limited to the intensification of the planar SPO (by transposition) in response to continued pure shear strain.

It is important to note that the above model need not be confined to rocks with very high megacryst modes. It was noted in Chapter III that some of the matrix grains may have already crystallised in a subjacent magma chamber prior to bulk transport to the level of the pluton. These grains, combined with others that would continue to crystallise as the magma cooled, would provide the sticky wall mechanism (when attached to megacrysts) required for fabric formation. Thus the same mechanism that formed the strong SPO foliations in the SIC may also have been active in the dikes.
INTRUSION HISTORY OF THE SIC AND DIKES

In the SIC, the vertical orientation of the lineations defined by the long axes of mafic matrix grains is thought to represent the escape direction of the remaining liquid upwards and away from the residual crystals. The steep to vertical dips of all of the SPO lineations, and the SPO foliations, are thought to represent a flow of magma with a major component in the present vertical. Large folds and other irregularities point to a less than ideal flow regime in the SIC. The presence of folded foliations in isolated material (Plate 4.5B) suggests that flow may have occurred in isolated pathways as the rocks progressively cooled, i.e. previously compacted, megacryst-rich rock was remobilised (from the dike walls) and retransported along the still open pathways in the dike. Transport along isolated channels (within otherwise consolidated rock) appears to have happened where circular arrangements of feldspar occur within material of the same composition with a strong foliation parallel to the dike walls. The ‘tube’ found in one of the outcrops might also represent a similar phenomenon. Foliation fabrics that deflect around xenoliths and mafic enclaves also suggest that some degree of the fabric was formed by a pure shear mechanism.

Similarly, some dikes at Aldermac possess SPOs and fabrics that clearly do not result from this idealised two-dimensional flow regime. The best evidence for this lies in the circles found in many of the dikes found intruded into the volcanic rocks south of the SIC. These circles probably represent a maturation of the transport regime over the cooling history of the dike. At some point in the history of the dike the bulk transport flow appears to have evolved to a state where transport of magma may have been confined to tubes whose outside diameter started equal to the dike width.

The most compelling petrographic and morphological evidence of the direction of magma transport, exists on the mill hill outcrop, where at least two dikes become narrower with increasing distance from the SIC. This narrowing is also coincident with a decrease in the modal feldspar megacryst content, with increasing distance from the SIC. These two features suggest that at least these dikes propagated away from the SIC, and have preserved features indicating transport of magma away from the SIC.

Overall, the dikes at Aldermac give an impression of the flow or transport of magma in the current vertical and away from the SIC. The suggestion that the dikes are
feeders for the SIC does not appear to be tenable (recall also the difference in granularity: phaneritic SIC rocks vs. aphanitic-porphyritic dikes). The coincident verticality of: SPO lineations, the dips of SPO foliations and the dips of most of the tabular bodies, suggests that the SIC and dikes have preserved their primary intrusion orientations. The main conclusions regarding flow directions are:

1. The SIC was intruded as a series of sheeted bodies of varying orientations, preserving flow line indicators in the present vertical.
2. The dikes within and surrounding the SIC generally preserve flow line indicators in the present vertical and horizontal.
3. Some of the dikes outside the SIC appear to have propagated away from the SIC.

The verticality of most of the structural features related to the SIC and its related dikes suggests that these bodies still possess their primary intrusion orientations. This is supported by a lack of evidence of penetrative deformation, jointing, or faulting within the SIC or the dikes.
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Table A1.1 Table of Dike orientation data in the Aldermac Mine area.

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Table A1.1 continued. Table of Dike orientation data in the Aldermac Mine area.

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**Amphibole Quartz Dikes (AQD)**

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**Quartz Feldspar Dikes (QFD)**

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**Quartz Amphibole Dikes (QAD)**

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Notes: spa. Denotes spacing between individual joints
stret. Denotes stretched
ves. Denotes vesicles
am. Denotes amygdules
Table A1.4 Table of foliation orientation data for the SIC.

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**Thin Section:** 6/25-2/1

**Type:** SIC

**Field Name:** biotite rich porphyry

**Facies:** BPS

**Date:** 1997-03-17

**Related Samples:** hand

**IUGS name:** apatite bearing aegirine-augite alkali feldspar syenite

---

### Main Mineralogy

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<thead>
<tr>
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<th>%</th>
<th>Granularity</th>
<th>Size Range (μm)</th>
<th>Typical Size (mm)</th>
<th>Colour in PPL</th>
<th>Colour in XPL</th>
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<td>grn</td>
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<td></td>
</tr>
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<td></td>
<td>x</td>
<td></td>
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<td></td>
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<tr>
<td>opaques</td>
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<td>0.1</td>
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<td>with biotite</td>
</tr>
<tr>
<td>mus</td>
<td>t</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
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### Textures

Feldspar: dusty; margins intergrown with mafics i.e. poikilitic enclosure; rare inclusions of titanite or bio; distorted simple twins common; perthitic; grain to grain contacts, separated by thin layer of mafics

Clinopyroxene: some simple twins, irregular margins, very fine 1-5 μm pale green needles growing off of grain ends – long axis parallel; small titanites and/or opaques as inclusions;

Other: biotite often rutilated; titanite twinned; apatite occurs in equant glomerocryst; section contains enclaves of biotite pyroxenite

---

### Fabric

feldspars have strong SPO; sparated by 2-4 grain thick mafic layers;

---

### Alteration

blue amphibole needles on pyroxene, un sericitised plag in unusual veins within feldspar megacrysts, does not penetrate matrix

Meg. Denotes megacryst; Mat. Denotes matrix.
### Main Mineralogy

<table>
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<tr>
<th>Name</th>
<th>%</th>
<th>Granularity</th>
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<th>Typical Size (mm)</th>
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<td>brn-grn</td>
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**Textures**

Feldspar megacrysts: simple twins common; dusty sericitisation; poikilitic margins; abundant inclusions; grains floating in matrix

Feldspar matrix: small interstitial; late growth

Mafics: phenocrystic texture; jammed together; intergrown

### Fabric

- strong feldspar megacryst SPO
- strong cpx SPO

### Alteration

Meg. Denotes megacryst; Mat. Denotes matrix.
Thin Section: 8/24-5/2
Type: SIC
Field Name: biotite pyroblte porphyry
Facies: BPS

Main Mineralogy

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<td>x</td>
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Textures

Feldspar Megacrysts: perthitic; dusty sericitic; clear rims of plag?; grain to grain contact common free of mafics; poikilitic margins

Feldspar matrix: fresh; includes plagioclase

Mafics: polygranular interstitial pods with anhedral feldspar

Fabric

strong feldspar megacryst SPO
well defined mafic enclave appears to deflect SPO fabric

Alteration

blue amphibole appears to grow off of ends of pyroxene grains
calcite replaces some feldspar matrix material; also fills late fractures in rock tit/apa bearing aegirine-augite alkali feldspar syenite

Meg. Denotes megacryst; Mat. Denotes matrix.
## Thin Section

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<td>bnr-grn</td>
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<td></td>
<td></td>
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## Textures

Feldspar: simple twins common; perthitic; dusty patches; poikilitic margins – more apparent on smaller grains; grain to grain contacts common

Aegirine-augite: some grains are lighter green in PPL or colourless in centres

Other: biotite typically contains opaques and rutile needles; some apatite grains with rust’ stained fractures

## Fabric

Feldspar SPO strong

## Alteration

Isolated patch of blue fibrous amphibole
Sericitisation of feldspar in patches

Meg. Denotes megacryst; Mat. Denotes matrix.
Thin Section: 6/21-3/4  Large: x  Date: 1997-06-24
Type: SIC  Reference: 
Field Name: biotite pyrobole syenite  Related Samples: hand, slab
Facies: BPS  IUGS name: biotite aegirine-augite akakli feldspar syenite

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<th>Typical Size (mm)</th>
<th>Colour in PPL</th>
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Textures
Feldspar: undeformed simple twins; grains intergrown; overgrown mafics in margins

Aegirine-augite: often individual floating grains; some intergrown glomerocrysts with biotite and opaques; some zoned grains with colourless (PPL) cores

Other: some mafic clots of bio, opaques + titanite; biotite rutilated with opaque inclusions

Fabric
strong feldspar SPO (trachytic)
matrix fabric deflects around larger mafic phenocrysts

Alteration
none

Meg. Denotes megacryst; Mat. Denotes matrix.
Thin Section: 6/21-4/2
Type: SIC
Field Name: prismatic porphyry
Facies: BPS

Main Mineralogy

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<th>Typical Size (mm)</th>
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<td>x</td>
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Textures

Feldspar megacrysts: simple twins common; zoned or cored; dusty patchy, perthitic highlights; enclose mafics at edges; grains fused together; margins between feldspars interdigitated

Feldspar matrix: common anhedral poikilitic feldspars enclosing mafics

Aegirine-augite: seriate; often floating in feldspar matrix

Other: common glomerocrysts of bio, cpx and titanite

Fabric

strong feldspar SPO

Alteration

dusty sericite in feldspars
blue amphibole needles on cpx

Meg. Denotes megacryst; Mat. Denotes matrix.
**Main Mineralogy**

<table>
<thead>
<tr>
<th>Name</th>
<th>%</th>
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<td>in bio</td>
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</table>

**Textures**

- Feldspar megacrysts: large grains perthitic; dusty; simple twins; poikilitic edges; fused grain to grain contacts

- Feldspar matrix: some twinned and perthitic, some plagioclase; all with irregular margins

- Biotite: some grains with small apatites, rutile and ?spinel

- Aegirine-augite: zoned; some calcite replacement

**Fabric**

- no visible SPO

**Alteration**

- calcite filled fractures
- calcite replacement patches in cpx and feldspar
- blue fibrous amphibole, felty vein on long edge of section

Meg. Denotes megacryst; Mat. Denotes matrix.
<table>
<thead>
<tr>
<th>Name</th>
<th>%</th>
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<th>Typical Size (mm)</th>
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</tbody>
</table>

**Textures**

Biotite: classic bio; pleochroic browns with some green in PPL

Aegirine-augite: fine anhedral matrix; some larger subhedral phenocrysts; one zoned phenocryst

**Fabric**

some preferred orientation of bio laths

**Alteration**

Meg. Denotes megacryst; Mat. Denotes matrix.
**Thin Section:** 6/12-H2  
**Type:** SIC  
**Field Name:** early porphyry  
**Facies:** BPS  
**Main Mineralogy**

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<th>Typical Size (mm)</th>
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<td>x</td>
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</tbody>
</table>

**Textures**

- Feldspar megacrysts: very dusty in patches; simple twins common; clear coronas i.e. not dusty; fused grains; inclusions of crystallographically oriented cpx common; fine birefringent crystallites (<0.1 mm) are crystallographically oriented as inclusions; single grain wide layer of mafics between feldspars

- Aegirine-augite: packed between feldspars or as interstitial clots; occasional porphyroblasts with opaques and apatite; some grains altering to fine blue amphibole near a vein in the thin section; some grains twinned and/or zoned; some anomalous interference colours

**Fabric**

- Strong feldspar SPO
- Log jams and local kinks in fabric form pockets full of mafics

**Alteration**

- Blue fibrous vein - opaques and amphibole alteration of cpx are localised near this vein

Meg. Denotes megacryst; Mat. Denotes matrix.
# Textures

- **Feldspar**: intergrown perthitic; poikilitic margins; some zoning; dusty cores, clear margins; some plagioclase

- **Aegirine-augite**: localised replacement by blue amphibole with needle protrusions from prism ends

## Fabric

- **strong feldspar SPO**
- **mafics isolated or in polygranular clots**

## Alteration

- **isolated portions of slide exhibit extensive replacement of cpx by blue alkali amphibole needles**;
- **calcite replacement patches in cpx and feldspar grains**

**Meg.** Denotes megacryst; **Mat.** Denotes matrix.
### Main Mineralogy

<table>
<thead>
<tr>
<th>Name</th>
<th>%</th>
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<th>Colour in PPL</th>
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<td>cubic</td>
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<td>x</td>
<td>x</td>
<td></td>
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<td>in bio?</td>
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</table>

### Textures

Feldspar: very dusty perthites; partial rims irregular and unaltered; orthoclase host; some subhedral plag grains in matrix; also some plain unaltered kspar; poikilitic margins on larger megacrysts

Biotite: some unusual grains with compositional differences in layers, shown by different pleochroism and interference colours; some composite grains

Other: muscovite often in vague radial groups and clusters

### Fabric

very strong feldspar SPO
matrix is polygranular and apparently random

### Alteration

calcite and qtz line a small fracture cutting through megacryst and matrix;
calcite grains in matrix
muscovite appears to be an alteration product

Meg. Denotes megacryst; Mat. Denotes matrix.
### Thin Section: 7/9-5B2

<table>
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<th>Related Samples: slab, hand</th>
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<td>GAS</td>
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### Main Mineralogy

<table>
<thead>
<tr>
<th>Name</th>
<th>%</th>
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<th>Size Range (mm)</th>
<th>Typical Size (mm)</th>
<th>Colour in PPL</th>
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<td>x</td>
<td></td>
<td>2</td>
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<td></td>
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<td>0.01</td>
<td>0.1</td>
<td>bl-grn</td>
<td>laths</td>
<td></td>
</tr>
</tbody>
</table>

### Textures

Feldspar megacrysts: mostly orthoclase; euhedral grains, many fragments; common zonation defined by 0.1mm anhedral inclusion in trains; very sharp margins, but some grains with dramatic embayments - 'swiss cheese' in hand sample; some grains with perthitic cores; some extensively replaced but crystallographically continuous grains; ingill of corrosion sometimes different grain size from adjacent matrix; rock appears to be cataclastic

Feldspar matrix: polygranular

Mafic matrix: subhedral amphibole laths in polygranular feldspar; some relict pyroxene grains

### Fabric

no megacrysts SPO
matrix SPO defects around (and into) grains

### Alteration

destruction of pyroxenes by?

Meg. Denotes megacryst; Mat. Denotes matrix.
Thin Section: 6/30-5/3
Type: SIC
Field Name: green enclave
Facies: GAS
Related Samples: slab
IUGS name: aegirine-augite bearing alk. amphibole perthite syenite

Main Mineralogy

<table>
<thead>
<tr>
<th>Name</th>
<th>%</th>
<th>Granularity</th>
<th>Size Range (mm)</th>
<th>Typical Size (mm)</th>
<th>Colour in PPL</th>
<th>Colour in XPL</th>
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<td>grn</td>
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</table>

Textures

Feldspar megacrysts: orthoclases, inclusions of crystallographically oriented needles; outer rim often rich in these needles, sometimes defining a corona; grains embayed as in rest of CGP

Feldspar matrix: anhedral; polycrystalline; some orthoclase and plag? visible

Mafic matrix: as for 7/9-5B2

Fabric

no feldspar SPO
strong SPO of amphiboles in matrix, deflects around megacrysts
contact between enclave and regular CGP is plastic

Alteration

Meg. Denotes megacryst; Mat. Denotes matrix.
## Main Mineralogy

<table>
<thead>
<tr>
<th>Name</th>
<th>%</th>
<th>Granularity</th>
<th>Size Range (mm)</th>
<th>Typical Size (mm)</th>
<th>Colour in PPL</th>
<th>Colour in XPL</th>
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<td>prisms</td>
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<td></td>
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<td></td>
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</table>

### Textures

Feldspars: some zoning defined by inclusions; simple twins; irregular poikilitic margins; some grains rounded; some fused grains.

Amphibole: some euhedral grains; typically anhedral with acicular ends, some replacement or continued growth.

### Fabric

moderate local feldspar SPO
interstitial pockets of randomly oriented mafics

### Alteration

abundant calcite in one feldspar;
fine acicular amphibole in patches

Meg. Denotes megacryst; Mat. Denotes matrix.
**Appendix A2**

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<td>IUGS name: aegirine-augite bearing alk amp alk feldspar syenite</td>
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### Main Mineralogy

<table>
<thead>
<tr>
<th>Name</th>
<th>%</th>
<th>Granularity</th>
<th>Size Range (mm)</th>
<th>Typical Size (mm)</th>
<th>Colour in PPL</th>
<th>Colour in XPL</th>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cpx</td>
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</tr>
</tbody>
</table>

### Textures

Feldspar: strongly perthitic yet some homogeneous; perthites have relict clear patches (20µm) that appear to be plag; may be simple sericitised plag slightly deformed simple twins; some bent grains, only one grain appears to be fractured and fused; coronas are rare; some poikilitic rims; rare amphibole porphyroblasts in interior of grains

Amphibole: layers between kspars, one grain wide to several grains wide; some in amphibole rich pockets

Other: final interstitial fill appears to be anhedral kspar (less dusty), cpx and ?

### Fabric

strong feldspar SPO

### Alteration

Meg. Denotes megacryst; Mat. Denotes matrix.
## Thin Section: 6/25-7/2

### Main Mineralogy

<table>
<thead>
<tr>
<th>Name</th>
<th>%</th>
<th>Granularity</th>
<th>Size Range (mm)</th>
<th>Typical Size (mm)</th>
<th>Colour in PPL</th>
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<td></td>
<td>brm</td>
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### Textures
- Feldspar: poikilitic margins; fused contacts; perthitic, dusty; some microcline
- Amphibole: in pockets, as single grain layers between kspars; often twinned; anomalous interference colours

### Fabric
- strong feldspar SPO
- strong amphibole SPO

### Alteration
- Meg. Denotes megacryst; Mat. Denotes matrix.
Appendix A2

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### Main Mineralogy

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<td>x</td>
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### Textures

Feldspar: typically zoned; some deformed simple twin planes; poikilitic margins; fused margins; dusty patchy alteration; isolated late plag; small orthoclases

Aegirine-augite: intergrown with amphibole; interstitial clusters or as layers between kspars

Amphibole: some laths appear primary; some acicular grains appear to be alteration of pyx

### Fabric

local cm scale feldspar SPO

### Alteration

dusty alteration of feldspars

Meg. Denotes megacryst; Mat. Denotes matrix.
Thin Section: 7/9-5B1  
Type: SIC  
Field Name: pink quartz porphyry  
Facies: QPS  

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Textures

Feldspar megacrysts: euhedral but many fragments; embayed or corroded as in CGP; numerous small inclusions defining zoning; sharp margins; orthoclase dominant; floating in matrix

Quartz: heavily embayed euhedral grains; some smaller grains appear rounded; floating in matrix

Fabric

no SPOs

Alteration

late quartz replacement near late vein; replacement qtz has undulose extinction

Meg. Denotes megacryst; Mat. Denotes matrix.
**Thin Section:** 7/3-3/1  
**Type:** SIC  
**Field Name:** pink porphyry  
**Facies:** AQS  
**Related Samples:** slab, hand  
**Date:** 1997-06-17  
**IUGS name:** alkali feldspar granite porphyry

### Main Mineralogy

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### Textures

Feldspars: zoned; simple twins; curved cleavage; some interstitial orthoclase

Quartz: interstitial; slightly deformed

### Fabric

weah feldspar SPO (strong in hand sample)

### Alteration

sulphides?  
brownish colouration on edges of some feldspars

Meg. Denotes megacryst; Mat. Denotes matrix.
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**Textures**

Feldspar megacrysts: zoned; patchy perthites; curved cleavage and crystal faces; unusual extinction figure; grains are damaged at point to face contacts

Feldspar matrix: clear, tartan twinned orthoclase

Quartz: slightly deformed; interstitial

**Fabric**

strong megacryst SPO

**Alteration**

one 8mm wide milky quartz vein with sharp margins; vein is deformed

Meg. Denotes megacryst; Mat. Denotes matrix.
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**Textures**

Feldspar megacrysts: zoned; perthitic; simple twins; unusual extinction; clevage planes symmetrically curved; grain to grain contacts common

Feldspar matrix: tartaned orthoclase

Mafics: appear to be pseudomorphing cpx prisms (or amphibole); cores filled by granoblastic feldspar

**Fabric**

strong feldspar SPO

**Alteration**

Meg. Denotes megacryst; Mat. Denotes matrix.
### Thin Section: 7/21-1/2G
- **Type:** volcanic
- **Field Name:** andesite
- **Facies:** na
- **IUGS name:** andesite
- **Date:** 1997-07-19

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</table>

**Textures**
- amygdules 0.05-1cm, filled with quartz, calcite and unidentified minerals; rock is heavily altered

**Alteration**
- chloritization of groundmass; sericitization of feldspars; amygdules
- sub-greenschist metamorphism

### Thin Section: 8/19-2/1G
- **Type:** volcanic
- **Field Name:** intermediate volcanic
- **Facies:** na
- **IUGS name:** intermediate volcanic
- **Date:** 1997-07-08

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**Textures**
- green cryptocrystalline groundmass with diffuse white streaks and patches (ghosts?)

**Alteration**
- chloritisation; destruction and replacement of phenocrysts
- sub-greenschist metamorphism

Meg. Denotes megacryst; Mat. Denotes matrix
### Appendix A2

**Thin Section:** 8/24-4/1G  
**Type:** volcanic  
**Field Name:** diorite?  
**Facies:** na  
**Related Samples:** slab, hand  
**IUGS name:** diorite/gabbro  
**Main Mineralogy**

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</table>

**Textures**

- intergrowths of mafics and opaques; groundmass is brown and cryptocrystalline

**Alteration**

- groundmass probably contained feldspars, now heavily sericitised;
- some mafics replaced by chlorite;
- sub-greenschist metamorphism

---

**Thin Section:** 8/23-3/2G  
**Type:** diabase dike  
**Field Name:** late diabase dike  
**Facies:** na  
**IUGS name:** gabbro (diabase)  
**Main Mineralogy**

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**Textures**

**Alteration**

- some plagioclase is heavily sericitised
### Thin Section: M8/24-1/2

**Type:** lamprophyre  
**Field Name:** lamprophyre  
**Facies:** na  
**IUGS name:** 'lamprophyre'

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**Textures**

**Alteration**

### Thin Section: 8/19-3/2G

**Type:** volcanic  
**Field Name:** equant porphyry  
**Facies:** na  
**IUGS name:** quartz bearing alakli amphibole monzonite/gabbro

<table>
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**Textures**

feldspars packed together separated by thin layers of amphibole; interstitial patches with anhedral feldspar and quartz and acicular amphibole; some cageworks of amphiboles; no SPOs

**Alteration**
### Main Mineralogy

<table>
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<th>Name</th>
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### Textures

Plag grains have polysynthetic twinning; zoning highlighted by dusty inclusions; some unusual sweeping extinction in XPL as seen in AQS; similar textures to 8/19-32G

### Alteration

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### Textures

Plag grains have polysynthetic twinning; zoning highlighted by dusty inclusions; some unusual sweeping extinction in XPL as seen in AQS; similar textures to 8/19-32G

### Alteration
### Main Mineralogy

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<th>Typical Size (mm)</th>
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#### Textures

- **Feldspar megacrysts:** euhedral, sharp margins; perthitic; rare inclusions of opaques; smaller grains with simple twins
- **Feldspar matrix:** irregular laths and 'needles; some in radiating clusters; 'fuzzy' texture
- **Mafics:** cpx and bio both look damaged – fringed with and include anhedral opaques; cpx is overgrown by and contains unknown high relief anhedral mineral; bio associated with unknown red mineral (oxide?)

### Fabric

- No visible feldspar SPO; matrix appears to be random

### Alteration

- See above (mafics)

Meg. Denotes megacryst; Mat. Denotes matrix.
Textures

Feldspar megacrysts: perthitic; dusty patches; multiple simple twins of multiple grains; clear rims; possible fragments

Feldspar matrix: fine clusters of needles/laths with irregular ‘fuzzy’ appearance

Mafics: cpx most grains are altered, some larger grains appear to be replaced by calcite; chlorite some large grains but most in polygranular clots probably replacing biotite

Fabric

No feldspar SPOs visible;
matrix appears to deflect around larger megacrysts

Alteration

chlorite replacing bio
cpx replaced by calcite

Meg. Denotes megacryst; Mat. Denotes matrix.
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<th>Granularity</th>
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<th>Typical Size (mm)</th>
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### Textures

Feldspar megacrysts: orthoclase, plagioclase, orthoclase; some complex intergrowths; some grains are zoned and dusty; some with inclusions; some with very sharp margins

Feldspar matrix: intergrown laths; abundant plagioclase

Mafics: opaques are skeletal, patchy and in aggregates; possible replacement of mafics; unknown mineral is skeletal and associated with other mafics

### Fabric

no SPOs

### Alteration

replacement of mafics?

Meg. Denotes megacryst; Mat. Denotes matrix.
Thin Section: 7-30-1/1  Large: x  Standard: Date: 1997-07-01
Type: dike  Reference:
Field Name: red porphyry dike  Related Samples: slab
Facies: ?  IUGS name:

**Main Mineralogy**

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**Textures**

Feldspar megacrysts: sharp margins; zoning highlighted by dusty regions and fine inclusions; some possible fragments; simple twins common

Feldspar matrix: anhedral, equant, polygranular

Mafics: often in radiating or subparallel growth aggregates, or as free individual grains in felsic matrix; unusual mafic grains with anomalous interference colours, look vaguely micaceous

**Fabric**

none

**Alteration**

? mafics

Meg. Denotes megacryst; Mat. Denotes matrix.
Thin Section: G9-8/1E  Large: x  Standard:  Date: 1997-06-30
Type: dike  Reference: 
Field Name: green porphyry dike  Related Samples: slab
Facies: BPD  IUGS name: chloritized aegirine-augite alkali feldspar trachyte

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**Textures**
Feldspar megacrysts: perthitic; zoned; simple twins; inclusions of pyx; margins very sharp – little embayment or overgrowth of matrix; possible fragments; some orthoclase

Feldspar matrix: very fine grained, polygranular

Mafics: cpx well-developed euhedral phenocrysts with some chloritization of fractures; some chlorite as individual grains, often rutilated; probable replacement of bio

**Fabric**
very strong feldspar SPO
strong cpx SPO

**Alteration**
late fractures; chloritization of cpx and bio – somewhat localised in slide

Meg. Denotes megacryst; Mat. Denotes matrix.
Appendix A2

Thin Section: 7/5-1B4
Type: dike
Field Name: green pyrobole dike
Facies: BPD
IUGS name: aegirine-augite alakli feldspar trachyte

Main Mineralogy

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Textures

Feldspar megacrysts: larger grains with shadowy twins, dusty cores; smaller grains clear with fine needle inclusions, occasional simple twins; some complex grains or aggregates; rare unusual sector twins

Feldspar matrix: very fine polygranular, subto anhedral laths and equant grains

Mafics: cpx fairly fresh – some brown staining on fractures/cleavage; abundant black cubic opaques in matrix

Fabric

moderate SPO defined by larger cpx grains
SPO parallel bands of cpx microlite rich matrix

Alteration

minor interstitial calcite; minor needles of ribbeckite

Meg. Denotes megacryst; Mat. Denotes matrix.
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**Main Mineralogy**

Feldspar magacrysts: simple twins, perthitic; some fragments; often grain to grain contacts or thin layer of matrix mafics - but little overgrowth of mafics; abundant fine needle inclusions

Mafics: chlorite with needle inclusions; cpx with cores with anomalous interference colours; some cpx altered

**Textures**

**Fabric**

moderate feldspar SPO
trachytic alignment of mafic needles with local deflections around feldspars

**Alteration**

pyroxenes contain calcite

Meg. Denotes megacryst; Mat. Denotes matrix.
Appendix A2

Thin Section: 8/3-1K2  
Large: Standard: x  
Date: 1997-07-02

Type: dike  
Field Name: "lamprophyre"  
Related Samples: hand, slab  
Facies: BPD  
IUGS name: pyroxene biotite alkali feldspar syenite (altered)

Main Mineralogy

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<th>Typical Size (mm)</th>
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</table>

Textures

Feldspar: heavily damaged but optically continuous, poikilitic?, some coarse orthoclase texture

Mafics: appears to contain cpx pseudomorphs up to 2 mm long now chloritised; abundant polygranular radiating chlorite between larger traceable feldspar grains

Fabric

Alteration

heavily altered porphyry, mostly chloritised

Meg. Denotes megacryst; Mat. Denotes matrix.
Appendix A2

**Type:** dike  
**Reference:**  
**Field Name:** blue porphyry dike  
**Related Samples:** hand  
**Facies:** BAD  
**IUGS name:** biotite alkali amphibole alkali feldspar syenite

### Main Mineralogy

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</table>

### Textures

- **Feldspar megacrysts:** dusty, perthitic, clear rims; some overgrowth of mafics; simple twins; inclusions of amphibole in centres; some zoning

- **Feldspar matrix:** subhedral laths, possible plagioclase; fuzzy texture; interlocking - polygranular

- **Amphibole:** fine needles and larger euhedral prisms appear primary

### Fabric

- Strong feldspar SPO

### Alteration

- Calcite in feldspar megacrysts and in matrix

Meg. Denotes megacryst; Mat. Denotes matrix.
**Thin Section:** 6/18-1/1  
**Type:** dike  
**Field Name:** qfp  
**Facies:** QFD  
**IUGS name:** quartz phenocryst bearing monzonite  
**Reference:**  
**Related Samples:** slab  
**Date:** 1997-07-27

### Main Mineralogy

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<tr>
<th>Name</th>
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<th>Granularity</th>
<th>Size Range (mm)</th>
<th>Typical Size (mm)</th>
<th>Colour in PPL</th>
<th>Colour in XPL</th>
<th>Notes</th>
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<td></td>
<td>blu-vio</td>
<td>fibrous</td>
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</table>

### Textures

Feldspar megacrysts: orthoclase, perthites, plag – all anhedral to euhedral; smaller grains usually subhedral, unusual twinning present; perthites are dusty; smaller grains are intergrown; smallest grains are anhedral

Quartz: zoning around edges defined by trains of anhedral inclusions

### Fabric

no feldspar SPO  
SPO defined by long axes of euhedral qtz phenocrysts

### Alteration

calcite in feldspar megacrysts and in matrix  
rare grains of blue amphibole

Meg. Denotes megacryst; Mat. Denotes matrix.
APPENDIX A3: FOLIATION CHARACTERISATION AND TESTS

INTRODUCTION
This appendix will focus on the methods of measurement of the strike and/or dip of SPO defined foliations and their degree of alignment (fabric intensity).

PART I:
CLASSIFICATION OF DEGREE OF ALIGNMENT
While foliation fabrics are common in the Syenite Igneous Complex (SIC) and related dikes, their degree of development, i.e. fabric intensity, can vary, ranging from very poor to very strong parallel orientations of feldspar megacrysts. In lieu of image analysis or detailed measurements for every outcrop, a simple method of estimation of the fabric intensity was deemed suitable for the purposes of this study. After preliminary mapping of the Syenite Igneous Complex (SIC), a numeric scale was devised ranging from 0, representing no visually determined orientation of megacrysts, to 5, representing a very strong parallel arrangement of feldspars. (Note that this system was devised for the dominantly two-dimensional exposure found in the Alderac Mine area and therefore is typically used to denote the fabric intensity in two dimensions only). This numeric scale and its descriptive equivalents are presented in Table A3.1. An attempt to calibrate the descriptive fabric intensity is presented in Part II of this appendix. Throughout the main text of this study, descriptive classifications of fabric intensity are followed by a numeric value in square parentheses, e.g. “very well developed [5] foliation”.

PART II:
MEASUREMENT METHODS AND CALIBRATION OF CLASSIFICATION SCHEME
In order to investigate the orientations of SPO foliation fabrics over the area of the entire SIC and its related dikes, a quick and reliable method of measurement was required. As with most field measurements of structural data, a compass (Brunton transit) was used to measure the orientations of the strike and dip (if visible) of the foliation plane, defined by the shape preferred orientation of tabular feldspar megacrysts. The degree of foliation or degree of parallel alignment of megacrysts in the foliation plane can vary dramatically
from outcrop to outcrop or even across an individual exposure. This factor presents a problem in the visual estimation of the mean trend of the foliation in an outcrop where the megacrysts are in a subparallel arrangement. A simple test was devised to test the accuracy of the author’s field estimation of these foliation fabrics.

**Procedure**

Two workers made independent measurements of the foliation on a typical outcrop exposure (following the same procedure used throughout the field area, i.e. visual estimation of the mean plane). The test involved the following procedure:

1. A 30 cm diameter circle was marked off.
2. An individual feldspar was chosen at random (with eyes closed).
3. An accurate measurement of the strike of the longest axis of the feldspar was made (using a Brunton transit), and recorded.
4. Measurements were made for 50 feldspar grains within the marked circle.
5. Data was processed using the Spheristat 2.1 computer program, and the mean orientation calculated.

This procedure was repeated twice, testing the method on an outcrop with a very strong parallel arrangement of feldspar grains [5] and on an outcrop with a moderate [3] parallel arrangement of feldspars.

The same procedure was also carried out on another outcrop where a true vertical face was exposed, allowing for the estimation and measurement of the true dip of the SPO foliation. The close proximity of the vertical face and horizontal face provided a good opportunity to test this visual estimation technique on both horizontal and vertical faces and compare the results. The SPO on this exposure has well-developed parallel arrangement of feldspars [4] in both the horizontal and vertical planes.

**Results**

The results of the three tests are shown in Table A3.2. Raw data are shown in Table A3.3. The rose diagrams for Tests 1 and 2 are shown in Figure A3.1A and B. The rose diagrams for Test 3 (the strike and dip test) are shown in Figure A3.1C and D. Note the
narrow distribution of values for Test 1, the very well developed foliation (Class [5]), and the bimodal distributions for Test 2 (a Class [3] foliation). The small peaks at a high angle to the main peak(s) are caused by rare grains oriented perpendicular or oblique to the main foliation (recall Plate 3.2B and Plate 3.6C).

Discussion

The results indicate a reasonable agreement between the authors' estimated measurements of foliations, and the values derived from careful measurements and statistical analyses. A maximum error of 1.4 % of the statistical values for foliation orientations is deemed acceptable for the purposes of this investigation.
Table A3.1. Classification of fabric intensity for SPO foliations in the Aldermac Mine area.

<table>
<thead>
<tr>
<th>Descriptive Intensity</th>
<th>Numerical Classification</th>
<th>Examples</th>
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<tr>
<td>Random (apparent)</td>
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<tr>
<td>Very weak</td>
<td>[1]</td>
<td>Plate 4.1C</td>
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<td>Poorly developed</td>
<td>[2]</td>
<td>Plate 4.7A</td>
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<tr>
<td>Moderate</td>
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<td>Plate 4.1D</td>
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<tr>
<td>Well developed</td>
<td>[4]</td>
<td>Plate 4.1A</td>
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<tr>
<td>Very well developed</td>
<td>[5]</td>
<td>Plate 4.6B</td>
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Table A3.2. Table of results for the calibration of estimated strike and dip readings for SPO defined foliation fabrics in the SIC.

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<th>Estimation</th>
<th>Class</th>
<th>Resultant strike</th>
<th>Resultant dip</th>
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*calculation based on the difference between the author’s estimation and the resultant vector calculated by Spheristat 2.1.
Table A3.3 Table of foliation calibration test data.

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</table>
Figure A3.1. Frequency rose diagrams for the orientation of SPO foliations tested in Appendix A3, Part II.

(A) Test 1: Strike measurements of 50 individual feldspar grains in a Class [5] foliation. Measurements are on a horizontal surface. Note the small spread of values, i.e. narrow propeller.

(B) Test 2: Strike measurements of 50 individual feldspar grains in a Class [3] foliation. Measurements are on a horizontal surface. Note the wider spread of values compared to A, and the bimodal distribution. There are two small peaks, which represent feldspars that are oblique to the main foliation trend.

(C) Test 3: Strike measurements of 50 individual feldspar grains in a Class [4] foliation. Measurements are on a horizontal surface.

(D) Test 3: Dip measurements of 100 individual feldspar grains in a Class [4] foliation. Measurements are on a vertical surface, which is directly adjacent and perpendicular to the surface used in C. All values are unweighted.
APPENDIX A4: A REVIEW OF SYENITES

The following is a brief review of syenite mineralogy and geochemistry; most of the material is taken from Williams et al. (1982), Hyndman (1985), and Deer et al. (1992). Syenites and nepheline syenites are typically white to pale gray to buff in colour and are often coarse grained with a trachyloid (pilotaxitic) texture, commonly formed by the alkali feldspars. Nepheline syenites (and monzonites) are commonly medium-grained and possess a massive texture.

Collectively, syenites and nepheline syenites can be broadly characterized into two groups based on their alkalis to alumina ratios. Syenites and nepheline syenites where the ratio \((\text{Na}_2\text{O} + \text{K}_2\text{O})/\text{Al}_2\text{O}_3\) is less than or equal to 1, are termed *miaskitic*. These rocks are rich in alkali feldspars and nepheline, and their more mafic members commonly contain biotite, with (or replaced by) aegirine or an Na-amphibole (kaersutite or hastingsite). Mafic members may also contain olivine or titanaugite. See Table 3.1 for the names, formulas, and distinctive properties of minerals found in syenites and trachytes.

Those syenites and nepheline syenites where the ratio \((\text{Na}_2\text{O} + \text{K}_2\text{O})/\text{Al}_2\text{O}_3\) is greater than 1 (i.e. excess alkalis or peralkaline), are termed *agpaitic*. They are primarily composed of alkali feldspar and some peralkaline minerals including sodalite, aegirine or alkali amphiboles. Minor minerals can include nepheline, natrolite, analcime, eudialyte, ramsayite, rinkolite and Na-silicates with high Zr, Ti, and REE contents (Hyndman, 1985).

Syenites (sensu stricto) are the medium to coarse-grained equivalents of trachytes. Alkali feldspars make up at least two thirds of all feldspar present, and, while minor quartz or feldspathoids may be present, commonly they are both absent. Syenites are typically present where erosion has cut through a volcanic pile containing related alkalic volcanic rocks. They can be grouped into two broad classifications based on their weight percent oxide ratios \((\text{K}_2\text{O}+\text{Na}_2\text{O})/\text{CaO}: 1)\) alkali syenites, and 2) alkali-lime syenites.

Where the ratio \((\text{K}_2\text{O}+\text{Na}_2\text{O})/\text{CaO}\) is high, alkali feldspars will represent no less than 95% of the total feldspars present. These *alkali syenites* typically occur as small plutons spatially associated with trachytes and phonolites. Micro- or cryptoperthites,
where orthoclase or microcline hosts albite or sodic oligoclase, are common in most alkali syenites. If present, quartz occurs interstitially, typically ranging in modal percent from 5-8%. The main mafic constituents can be: iron-rich biotite or hornblende, or any of the sodic pyrobes, hastingsite, aegirine-augite, aegirine, arvedsonite or riebeckite. Commonly present as accessories are titanite,apatite, zircon, and opaque iron oxides.

Two minor subdivisions of alkali syenites exist: 1) In peraluminous alkali syenites (oxides $\text{K}_2\text{O}+\text{Na}_2\text{O}+\text{CaO} > \text{Al}_2\text{O}_3$) the dominant minerals are microperthite, biotite and muscovite, and when truly aluminium rich they may contain abundant accessory corundum as well as aluminous minerals such as spinel, chrysoberyl and pyrope garnet; 2) Peralkaline alkali syenites (oxides $(\text{K}_2\text{O}+\text{Na}_2\text{O}) > \text{Al}_2\text{O}_3$), also contain microperthite, but the mafic minerals will be iron and sodium-rich i.e. arvedsonite and aegirine. They may also contain minor nepheline.

If emplaced at shallow depths, alkali syenites can contain sanidine rather than orthoclase or microperthite. In mafic varieties of alkali syenite, transitional into shonkinites, melanite garnet may be abundant.

Where the ratio $(\text{K}_2\text{O}+\text{Na}_2\text{O})/\text{CaO}$ is low, (i.e. rocks of a less alkaline nature than true alkali syenites), sodic plagioclase will account for 5-30% of the modal feldspar, typically in the form of oligoclase or andesine, and less commonly labradorite (significantly calcic). These alkali-lime syenites occur as medium to coarse grained phaneritic rocks as well as porphyries. In coarser grained rocks the dominant feldspar is a micro- or cryptoperthite where the host mineral is orthoclase (rarely microcline). Perthitic intergrowths are less common in microsyenites and syenite porphyries, where the dominant alkali feldspar is sodic orthoclase or sanidine.

If quartz is present it will commonly occur as anhedral interstitial grains, but can also be found in micrographic intergrowth with potassic feldspar, or in myrmekite. Brown biotite and green hornblende are characteristic mafic minerals in alkali-lime syenites, and are predominantly found together. In quartz bearing varieties, biotite will modally dominate hornblende, while the reverse occurs in most other varieties. Occurring as discrete crystals or as cores in hornblende, diopsidic augite becomes more abundant as syenites become more basic. Orthopyroxene, olivine and titaniferous augite are rare but
do occur in syenites transitional to monzonites and alkali gabbros. Minor accessories in alkali-lime syenites are generally less abundant and less varied than those found in alkali syenites; these can include: apatite, sphene, zircon, and opaque oxides (less titanium than oxides in alkali syenites).

Feldspathoidal Syenites (sensu stricto) are the plutonic equivalents of phonolites; they contain alkali feldspar and a feldspathoid as their principal components. Their best-known occurrences are as principal components of subvolcanic ring complexes in stable continental cratons, where they are associated with essexites and ijolites. They may also be found as small plugs or ring dikes in eroded volcanic eruptive centres, where they are secondary to basanite, nephelinite and phonolite lavas.

Feldspathoidal syenites typically have an intermediate weight percent SiO$_2$ content, but this can vary depending on whether feldspathoids or alkali feldspars dominate the rock. They are typically rich in sodium. This is seen in the predominance of the sodic feldspathoids: (in order of greatest abundance) nepheline, analcime, sodalite, nosean (rare); as well as the sodic feldspars perthite, antiperthite and albite, and sodic mafic minerals such as aegirine-augite, aegirine, arfvedsonite, and ferropargasitic hornblende. If present, biotite will be iron and titanium rich, and common opaque oxides will also be titanium rich. Other common and abundant minerals can include apatite, zircon, sphene, melanite garnet, and zirconium- and titanium-bearing silicates. Deuteric cancrinite and calcite can also be found. Titanaugite can be common in more basic varieties of feldspathoidal syenites, and olivine may also be present. Peraluminous varieties can commonly contain corundum and muscovite. Orthopyroxene is invariably absent in all varieties.

A typical feldspathoidal syenite, i.e. a nepheline syenite, has little or no plagioclase, and subequal amounts of alkali feldspar and a feldspathoid (nepheline). Nepheline is commonly euhedral to subhedral and poikilitically enclosed by sodic orthoclase or microperthite. The principal mafic mineral will be aegirine-augite, but aegirine, hornblende, or biotite may predominate. Apatite, sphene and titanium- and iron-rich oxides will invariably be present.
Peralkaline feldspathoidal syenites will have a potassium feldspar and a distinctive alkali-rich, alumina-poor, mafic mineral such as arfvedsonite, eckermannite and aegirine. These rocks may be unusually rich in apatite and sphene as well as the zirconium minerals: eudialyte, catapleite, rosenbuschite, lavenite, and zircon.

Shonkinites or mafic rich potassium feldspar-bearing feldspathoidal syenites are variants of the feldspathoidal syenite family and best labeled as such. A typical member will contain sanidine, augite, biotite, mixed zeolites and carbonates, and minor apatite and opaques. These rocks are best treated as members of the K-rich (shoshonitic) petrological association.
Mean modal feldspar megacryst content of dikes

- 0-25 %
- 26-50 %
- 51-75 %
- 76 % +
Map 1.2
Detailed Geology of the Mill Hill Exposure, Aldermac, Quebec

Legend

Lithology

- [ ] Biotite-Pyroline Dikes (BPD); visible contact, interpreted contact
- [ ] Biotite-Pyroline Syenite (BPS); visible contact, interpreted contact
- [VF,I] Volcanics; mixed felsic and intermediate.

Symbols

- [o] Outcrop
- [86°] Dike dip
- [ ] Dike crosscutting relationship; longer line segment is parallel to younger dike
- [x] Volcanic xenoliths in dike
- [©] Circular arrangement of feldspar megacrysts
- [j] Connected jog in dike
- [f] Fine grained feldspar megacrysts; < 1 mm
- [m] Medium grained feldspar megacrysts; 1-5 mm
- [c] Coarse grained feldspar megacrysts; 6-10 mm
- [v] Very coarse feldspar megacrysts; 11-30 mm
- [VV] Extra coarse feldspar megacrysts; > 30 mm
NOTE TO USERS

Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

UMI
Detailed geology of the Lucky area

Lithology
- Pyroxene Amph: coarse amphib
- Pyroxene Amph: fine grained amphib
- Biotite Amph
- Green Amphib
- Quartz Phryic
- Amphibole Qu
- Amphibole Qu: amphibole rich
- Amphibole Qu: quartz rich variety
- Quartz Amphib
- Quartz Feldspar

Symbols
- Foliation; dip
- Joint; inclined
- Quartz vein; dip
- Blue amphibole
- Contact, visible
- Contact, interpreted
MAP 1.3
Detailed geological map of the Lucky Swine Outcrop

Legend

Lithology
- Pyroxene Amphibole Syenite (PAS); coarse amphibole variety
- Pyroxene Amphibole Syenite (PAS); fine grained amphibole variety
- Biotite Amphibole Syenite (BAS)
- Green Amphibole Syenite (GAS)
- Quartz Phryic Syenite (QPS)
- Amphibole Quartz Syenite (AQS)
- Amphibole Quartz Syenite (AQS); amphibole rich variety
- Amphibole Quartz Syenite (AQS); quartz rich variety
- Quartz Amphibole Dike (QAD); inclined, vertical
- Quartz Feldspar Dike (QFD); inclined, vertical

Symbols
- Foliation; dip unknown, inclined, vertical
- Joint; inclined, vertical
- Quartz vein; dip unknown, inclined
- Blue amphibole stringer vein; dip unknown, inclined
- Contact, visible
- Contact, interpreted or buried
Small rose diagrams of foliation trends for individual groups of outcrops

Overall feldspar foliation trend
Green Amphibole Syenite (GAS)
Quartz Phryic Syenite (QPS)
Amphibole Quartz Syenite (AQS)
Amphibole Quartz Syenite (AQS); amphibole rich variety
Amphibole Quartz Syenite (AQS); quartz rich variety
Quartz Amphibole Dike (QAD); inclined, vertical
Quartz Feldspar Dike (QFD); inclined, vertical

Symbols
Foliation; dip unknown, inclined, vertical
Joint; inclined, vertical
Quartz vein; dip unknown, inclined
Blue amphibole stringer vein; dip unknown, inclined
Contact, visible
Contact, interpreted or buried

Notes
Small rose diagrams on map indicate feldspar foliation trends for individual outcrops or groups of outcrops.

Overall feldspar foliation trend
Overall visible contact trend
NOTE TO USERS

Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

UMI
MAP 1.1

GEOLOGY OF T. ALDERMAC MINE.

Scale 1:4000

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ROCK TYPE LABELS

Main category, i.e.
Syenite pluton

Rock (facies) type, i.e. BPS
(see lithological legend)

S1p

Mean megacryst
grain size, i.e. coarse

Descriptive modifier,
I.e. prismatic megacrysts

Range containing mean
megacryst mode; i.e. 0-25%

Main category, i.e. volcanics

Rock type, i.e. mixed felsic and
intermediate rocks

VF,l

(a) Accessories or Textures,
i.e. amygdaloidal

LEGEND

LITHOLOGY

LABEL MC
MAP 1.1

GEOLOGY OF THE ALDERMAC MINE AREA

Scale 1:4000

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ROCK TYPE LABELS

Main category, i.e. Syenite pluton

Mean megacryst grain size, i.e. coarse

Rock (facies) type, i.e. BPS (see lithological legend)

Descriptive modifier, i.e. prismatic megacrysts

Range containing mean megacryst mode; i.e. 0-25%

Main category, i.e. volcanics

Rock type, i.e. mixed felsic and intermediate rocks

Accessories or Textures, i.e. amygdaloidal

EXAMPLE OF A PLUTONIC ROCK LABEL

EXAMPLE OF A VOLCANIC ROCK LABEL

LEGEND

LITHOLOGY

LABEL MODIFIERS (VOLCANICS)
POST-ARCHEAN INTRUSIONS

**Diabase dîke ("Late Gabbro")**

SYENITE/TRACHYTE DIKES

- Quartz-Amphibole Dike (QAD)
- Quartz-Feldspar Dike (QFD)
- Amphibole-Quartz Dike (AQD)
- Biotite-Amphibole Dike (BAD)
- Biotite-Pyroxene Dike (BPD)

SYENITE IGNEOUS COMPLEX (SIC)

- Biotite-Pyroxene Syenite (BPS)
- Pyroxene-Amphibole Syenite (PAS)
- Biotite-Amphibole Syenite (BAS)
- Green Amphibole Syenite (GAS)
- Quartz Phrylic Syenite (QPS)
- Amphibole-Quartz Syenite (AQS)

ARCHEAN VOLCANIC ROCKS

- Andesite
- Rhyolite
- Basalt
- Gabbro/Monzonite
**LITHOLOGY**

**POST-ARCHEAN INTRUSIONS**

- Diabase dike ("Late Gabbro")

**SYENITE/TRACHYTE DIKES**

- Quartz-Amphibole Dike (QAD)
- Quartz-Feldspar Dike (QFD)
- Amphibole-Quartz Dike (AQD)
- Biotite-Amphibole Dike (BAD)
- Biotite-Pyroxene Dike (BPD)

**SYENITE IGNEOUS COMPLEX (SIC)**

- Biotite-Pyroxene Syenite (BPS)
- Pyroxene-Amphibole Syenite (PAS)
- Biotite-Amphibole Syenite (BAS)
- Green Amphibole Syenite (GAS)
- Quartz Phyric Syenite (QPS)
- Amphibole-Quartz Syenite (AQS)

**ARCHEAN VOLCANIC ROCKS**

- Andesite
- Rhyolite
- Basalt

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**LEGEND**

**LABEL MODIFIERS (VOLCANICS)**

- Epidote mineralization
- Pyrite mineralization
- Quartz mineralization
- Sulphide mineralization

**TEXTURES**

- Amygdaloidal texture
- Volcanic breccia
- Gossan zone
- Silicified
- Volcanic tuff
- Vesicles

**LABEL MODIFIERS (SIC)**

- Mottled (alteration effect)
- Bimodal megacryst sizes
- Mafic enclaves
- Matrix dominated
- Prismatic feldspar habit
V2 Rhyolite
V3 Basalt
V4 Gabbro/Monzonite
V5 Diorite
VF Felsic Volcanic Rocks
VI Intermediate Volcanic Rocks
VM Mafic Volcanic Rocks
LA Lamprophyre

SYMBOLS

Dike; dip unknown, inclined, vertical (see lithology legend for colour coding)
Blue amphibole stringer vein; dip unknown, inclined
Milky quartz vein; dip unknown, inclined
Joint; inclined, vertical
Bedding, top unknown; inclined, vertical
Bedding, top indicated by arrow; inclined
Foliation, mineral SPO defined; dip unknown, inclined, vertical
Lineation, mineral SPO defined; vertical or subvertical
Marsh or Swamp
Building or foundation, mine shaft
River, shoreline

NOTES
a Dikes are shown with unlined, inclined strike.
b All cross-sections are drawn to scale.
c Lithology codes in figure refer to legend in report.
d A dark outline on some symbols indicates an exposure.
e A dark outline on some symbols indicates a mine.
f Esotes in names indicate added information.
### SYMBOLS

- **Dike; dip unknown, inclined, vertical**
  - (see lithology legend for colour coding)

- **Blue amphibole stringer vein; dip unknown, inclined**

- **Milky quartz vein; dip unknown, inclined**

- **Joint; inclined, vertical**

- **Bedding, top unknown; inclined, vertical**

- **Bedding, top indicated by arrow; inclined**

- **Foliation, mineral SPO defined; dip unknown, inclined, vertical**

- **Lineation, mineral SPO defined; vertical or subvertical**

- **Marsh or Swamp**

- **Building or foundation, mine shaft**

- **River, shoreline**

### MEGACRYST GRAIN SIZE

- **Fine; <1 mm**

- **Medium; 1 - 5 mm**

- **Coarse; 6 - 10 mm**

- **Very coarse; 11 - 30 mm**

- **Extra coarse; >30 mm**

### MEAN MODAL MEGACRYSTS (%)

- **0 - 25 %**

- **26 - 50 %**

- **51 - 75 %**

- **76 - 100 %**

### NOTES

- **a** Dikes are grouped into igneous facies based on modal matrix content. All dikes contain feldspar megacrysts.

- **b** All rocks in the Syenite Igneous Complex (SIC) are grouped into igneous facies based on modal matrix content. All facies contain feldspar megacrysts. Some felsic facies range into the alkali feldspar granite field.

- **c** Volcanics category includes early concordant intrusives. Most volcanic rocks are heavily silicified and unidentifiable in hand sample.

- **d** Label modifiers for volcanics are shown in parentheses, in conjunction with rock type labels (see above explanatory diagram).

- **e** Label modifiers for SIC rocks are shown in conjunction with rock type labels (see above explanatory diagram). Modifiers consist of: 1) descriptive modifiers, 2) mean grain size of feldspar megacrysts, and 3) mean megacryst modal content.

- **f** Estimate of the mean grain size of feldspar megacrysts in a typical sample of rock in the area.
Blue amphibole stringer vein; dip unknown, inclined

Milky quartz vein; dip unknown, inclined

Joint; inclined, vertical

Bedding, top unknown; inclined, vertical

Bedding, top indicated by arrow; inclined

Foliation, mineral SPO defined; dip unknown, inclined, vertical

Lineation, mineral SPO defined; vertical or subvertical

Marsh or Swamp

Building or foundation, mine shaft

River, shoreline

Gravel road

Trail or cut line

Mine tailings; boundary

Outcrop code

Geological contact

Outcrop Exposure

Fault

- Dikes are grouped into igneous facies based on modal matrix content. All dikes contain feldspar megacrysts.

- All rocks in the Syenite Igneous Complex (SIC) are grouped into igneous facies based on modal matrix content. All facies contain feldspar megacrysts. Some felsic facies range into the alkali feldspar granite field.

- Volcanics category includes early concordant intrusives. Most volcanic rocks are heavily silicified and unidentifiable in hand sample.

- Label modifiers for volcanics are shown in parentheses, in conjunction with rock type labels (see above explanatory diagram).

- Label modifiers for SIC rocks are shown in conjunction with rock type labels (see above explanatory diagram). Modifiers consist of: 1) descriptive modifiers, 2) mean grain size of feldspar megacrysts, and 3) mean megacryst modal content.

- Estimate of the mean grain size of feldspar megacrysts in a typical sample of rock in the area.

- Symbols represent the range containing the mean modal content of feldspar megacrysts for a typical rock in the area.

**SOURCES OF INFORMATION**

Some volcanic contacts modified from:

Base map derived from topographic maps by Energy, Mines and Resources Canada, and aerial photographs.

**ACKNOWLEDGMENTS**

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**CREDITS**