DALHOUSIE UNIVERSITY

Investigating possible hybridization of the Peggys Cove granite section of the Halifax Pluton, South Mountain Batholith, Nova Scotia

Sydney Stashin

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF BACHELOR OF SCIENCES, HONOURS
DEPARTMENT OF EARTH SCIENCES
DALHOUSIE UNIVERSITY, HALIFAX, NOVA SCOTIA

April 2017

Distribution License

DalSpace requires agreement to this non-exclusive distribution license before your item can appear on DalSpace.

NON-EXCLUSIVE DISTRIBUTION LICENSE

You (the author(s) or copyright owner) grant to Dalhousie University the non-exclusive right to reproduce and distribute your submission worldwide in any medium.

You agree that Dalhousie University may, without changing the content, reformat the submission for the purpose of preservation.

You also agree that Dalhousie University may keep more than one copy of this submission for purposes of security, back-up and preservation.

You agree that the submission is your original work, and that you have the right to grant the rights contained in this license. You also agree that your submission does not, to the best of your knowledge, infringe upon anyone's copyright.

If the submission contains material for which you do not hold copyright, you agree that you have obtained the unrestricted permission of the copyright owner to grant Dalhousie University the rights required by this license, and that such third-party owned material is clearly identified and acknowledged within the text or content of the submission.

If the submission is based upon work that has been sponsored or supported by an agency or organization other than Dalhousie University, you assert that you have fulfilled any right of review or other obligations required by such contract or agreement.

Dalhousie University will clearly identify your name(s) as the author(s) or owner(s) of the submission, and will not make any alteration to the content of the files that you have submitted.

If you have questions regarding this license please contact the repository manager at dalspace@dal.ca.

Grant the distribution license by signing and dating below.

______________________________	______________________________
Name of signatory	Date

DALHOUSIE UNIVERSITY

Department of Earth Sciences
Halifax, Nova Scotia
Canada B3H 4R2
(902) 494-2358

DATE: 28 April 2017

AUTHOR: Sydney Stashin

TITLE: Investigating possible hybridization of the Peggys Cove granite section of the Halifax Pluton, South Mountain Batholith, Nova Scotia

Degree: B. Sc. Honours Earth Sciences Convocation: May Year: 2017

Permission is herewith granted to Dalhousie University to circulate and to have copied for non-commercial purposes, at its discretion, the above title upon the request of individuals or institutions.

Redacted for Privacy

Signature of Author

THE AUTHOR RESERVES OTHER PUBLICATION RIGHTS, AND NEITHER THE THESIS NOR EXTENSIVE EXTRACTS FROM IT MAY BE PRINTED OR OTHERWISE REPRODUCED WITHOUT THE AUTHOR’S WRITTEN PERMISSION.

THE AUTHOR ATTESTS THAT PERMISSION HAS BEEN OBTAINED FOR THE USE OF ANY COPYRIGHTED MATERIAL APPEARING IN THIS THESIS (OTHER THAN BRIEF EXCERPTS REQUIRING ONLY PROPER ACKNOWLEDGEMENT IN SCHOLARLY WRITING) AND THAT ALL SUCH USE IS CLEARLY ACKNOWLEDGED.

ABSTRACT

This study performed an investigation of magmatic growth history of the K-feldspar megacrysts and plagioclase crystals in the Halifax Pluton, a Late Devonian age granite that intruded into the Meguma strata bedrock. We used the growth histories of these crystals to examine the extent of hybridization in three sections of the Halifax Pluton: Peggy's Cove, Prospect, and Sambro Head. Several outcrops in the Peggys Cove and Prospect section of the pluton contain clusters of large mafic enclaves, which differ texturally from country-rock, metasedimentary xenoliths, and appear to be of a magmatic origin. Of note are enclaves that show megacrysts crosscutting their margins, suggesting that both the host granite and enclave were at least partially liquid during megacryst growth and magma mixing could have occurred. A mafic dyke has been documented at Sambro Head, with several zones of magma mingling suggesting it was injected as a partial liquid into the granitic ground mass. This study used field observations, petrography, and detailed electron microprobe analysis to study the large K-feldspar megacrysts and smaller plagioclase crystals from the granite sections at Prospect, Peggys Cove, and Sambro Head. Samples from within the mafic dyke at Sambro Head were also analyzed. Evidence suggests that a variable extent of magma mixing/mingling and hybridization occurred and this is reflected in the different textures recorded by these megacrysts from each phase of the pluton. Evidence of chemical zoning preserved in the K-feldspar megacrysts and plagioclase crystals, especially where no obvious mafic enclaves or dykes are present, suggests that hybridization of this granitic pluton may have been more widespread than previously documented. The presence of mafic dykes does not necessarily provide evidence of mixing; on the contrary it is the absence of mafic dykes at these sites that indicate extensive hybridization may have occurred.

Key Words: megacryst, resorption, dyke, zoning, hybridization

TABLE OF CONTENTS

TABLE OF FIGURES

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my supervisor Richard Cox for his guidance on this project – from fieldwork to data analysis to critical commentary. Thank you to the Shell Fund for their generous funding, without which this research would not have been possible. Thank you to Barrie Clarke for tipping us off about the presence of the dyke feature at Sambro Head, allowing us to formulate this story further. Finally, I would like to thank Dalhousie and especially the members of the department of Earth Sciences for their support, and friendship.

CHAPTER 1: INTRODUCTION

1.1 Opening Statement

The aim of this study was to analyze the granitic K-feldspar megacrysts and the plagioclase crystals in three separate locations of the South Mountain Batholith in Nova Scotia for evidence of hybridization. Granitic suites of plutons have specific characteristics attained from the derivation of source material of a specific composition. Introducing magma mixing to these plutons is a complex process that involves disequilibrium in your granitic melt as two or more magmas of varying composition interact (Slaby & Gotze, 2004). When the compositions of pairs of suites mix, distinct differences appear, especially apparent in the crystal elemental composition as you traverse across the crystal from the core to the rim. We used field observations, petrography, and detailed electron microprobe analysis to study these suites of granites and their mafic intrusions to support the hypothesis that magma mixing and hybridization occurred throughout the Halifax Pluton.

1.2 Purpose and Objective

This study aims to examine the microtextural, geochemical, and elemental evolution of the granitic crystals in the granites in order to provide a better understanding of the factors that influence the development of heterogeneity in granites. Evidence of oscillatory zoning in major elements in particular has been hypothesized to suggest magma mixing/mingling, with previous research of granitic rock suites supporting this claim. We supported this hypothesis with further research in a three-part approach.

(1) Conducted fieldwork to identify and map textures and collect samples
(2) Performed lab work including petrographic analysis of thin sections collected from the field area or previous acquired (Wongus, 2013), and microprobe analysis of specific crystals of interest
(3) Established, based on observed textures, whether magma mixing could have occurred and to what extent.

1.3 Magmatic Processes and Textures in Hybridized Granites

The specific nature of mafic-felsic magma interactions (magma mixing and mingling) is an important element in understanding the dynamics of the magma chambers and their subsequent pluton emplacement. Evidence of hybridization of magmas, or magma mixing/mingling can be found in many granite bodies around the world, and observed in textures from the whole pluton down to a single crystal. Magma mixing implies some sort of physical and/or chemical interaction between melts of different compositions, which leads to disequilibrium conditions in which these crystals grow. This disequilibrium influences many different textures in the crystals, in particular their nucleation and growth rate as well as composition.

Feldspars are particularly susceptible to these sort of growth changes in the melt, and purposely used in order to deconstruct the melt histories and the histories behind their hybridization. The crystals grow under new conditions of pressure and temperature and recorded in their chemical signatures, oftentimes as zoning. Zoning, particularly oscillatory zoning, in K-feldspars can be observed most readily and some plagioclase crystals also show evidence of this pattern. These zones are generally a result of chemical variation within the crystal. Therefore, the composition and growth morphology of igneous feldspars reflects certain changes in their crystallization environment and can be excellent indications towards the growth histories of these magmatic plutons. They give a reliable record of the crystallization dynamics of the melt and its thermal and compositional turbulence.

Oscillatory zoning is a form of chemical zoning in which the chemical elements oscillate in a regular zones throughout a crystal (Long & Luth, 1986). Essentially, the presence of oscillatory zoning indicates rhythmic growth of the crystal as it circulates through the magma chamber. Oscillatory zoning combined with evidence of resorption and significant variations in temperature sensitive elements and mineral compositions suggests magma mixing and hybridization occurred.

Cox et al. (1996) observed barium oscillatory zoning growth textures in K-feldspar megacrysts in the Shap Granite, Northern England. He discovered within these K-feldspar megacrysts numerous barium rich zones that likely developed during periods of slight dissolution and regrowth (Cox et al. 1996). Upon reaching melting temperatures, a percentage of the mineral will convert from solid to liquid phase. As barium is an incompatible element, it will be more concentrated in the melt phase, subtracted from the solid phase. Cox et al. (1996) linked these sort of textures to multiple intrusions of basic magmas causing the hybridization of these magmas and subsequently the heterogeneity of the granites. Long and Luth (1986) studied this effect on the K-feldspar crystals in the Peñasco Quartz Monzonite and observed a pattern of oscillation in barium concentrations under increased temperatures. Their research suggested that barium concentrations within a K-feldspar megacrysts in relation to the diffusion coefficient could indicate the origin of a crystal and its subsequent growth history. Figure 1, a diagram from Long and Luth (1986) show K-feldspar traverse data and peaks of barium concentration across the megacryst. They observed that the size of the barium peaks (the higher concentrations) increase as the size of the megacryst decreases. They also attributed these spikes in barium to increases in temperature caused by multiple intrusions of magma into the pluton.

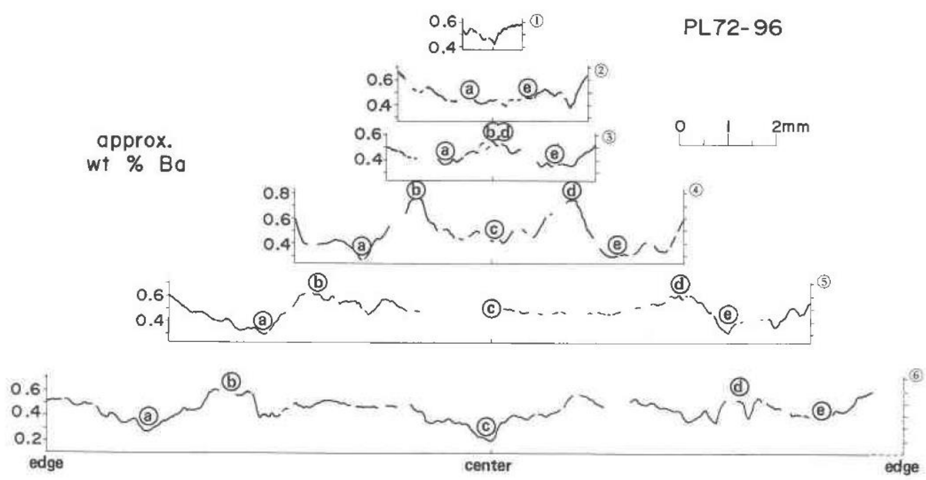


Figure 1. Diagram created by Long and Luth (1986). Depicts traverse data across K-feldspar megacrysts. Multiple barium peaks are shown across the megacrysts with a larger barium concentration increase as the size of the megacryst decreases.

Clark and Clark (1998) specifically looked to identify these textures in the South Mountain Batholith, the same location as our area of study. They concluded that similar processes occurred; K-feldspar megacrysts formed in magmatic conditions, under a range of pressure, temperature, and composition preserve the environmental history in their barium zoning textures as the crystal grows.

The typical zoning of igneous plagioclase can be distinguished from metamorphic plagioclase, in that igneous plagioclase proceeds from a calcic core to a sodic rim (Smith, 2012). This is because albite has a lower melting point that anorthite. Hills (1936) hypothesized a general explanation for the delicate and regular oscillatory zoning in plagioclase. They hypothesized that oscillations related to variations in the rates of crystallization and diffusion of these crystals led to recurrent supersaturation of anorthite in the melt.

Figure 2 depicts a generalized feldspar ternary diagram illustrating the possible range of plagioclase and alkali feldspar compositions in the melt. This diagram illustrates that as the average temperature increases, the compositions of feldspars growing in the melt can be much more potassium rich, developing a ternary composition. As the average temperature decreases, the composition of the plagioclase feldspars moves left into the lower temperature compositional boundary. The lowest average temperature melts will produce compositions that fall adjacent or directly along the An-Ab composition line on the left side of the ternary diagram.

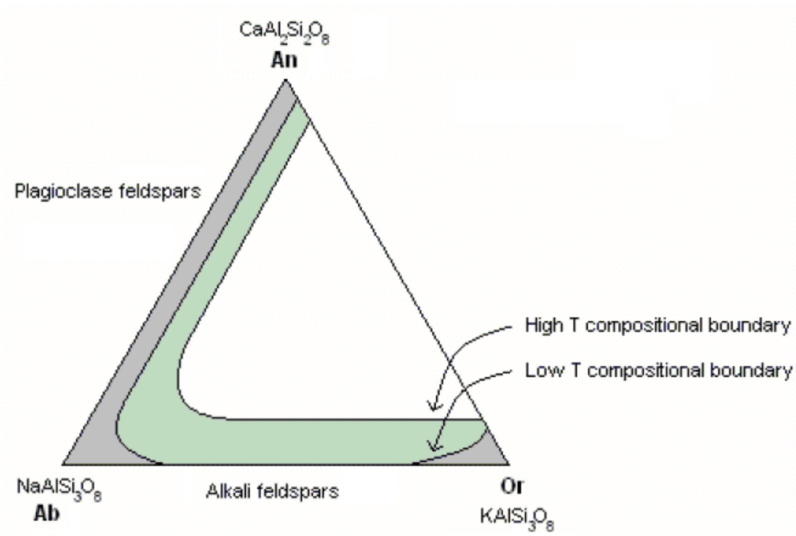


Figure 2. Diagram of Feldspar Tertiary Diagram. Depicting the zones of composition with higher to lower average temperatures of the melt. (Downs, 2013)

As described by Macdonald (1992), the South Mountain Batholith is a heterogeneous granitoid body. A number of possible explanations for heterogeneity in granitoid rocks have been proposed: crustal contamination, magma mixing, melt instability, and volatile interaction (Cox et al. 1996). This paper hypothesized that magma mixing was likely the cause of the textural and chemical patterns observed in the rocks. This study will focus on K-feldspars and plagioclase crystals in the growth of three separate areas of the Halifax Pluton, in order to deconstruct the particular hybridization that occurred throughout the granitoid body.

CHAPTER 2: GEOLOGICAL SETTING

2.1 Regional Setting

The geological history of Nova Scotia spans approximately 1.2 billion years and comprises a diverse display of the many time spans, especially exposed along the shorelines. The process of continental drift led to the creation of the Meguma Terrane; which was previous attached to Gondwana or present day Africa and now encompasses the southern half of the province's mainland portion (Fensome & Williams, 2001). Continental drift also created the northern half of the province that comprises the Avalon Terrane, once attached to present day Scandinavia and Scotland. The Meguma Terrane joined the present day North American landmass during the Appalachian orogeny, which also created the Appalachian Mountains currently exposed in the Northeastern United States (Fensome & Williams, 2001). The Meguma is composed mostly of Cambrian to Ordovician sedimentary deposits,

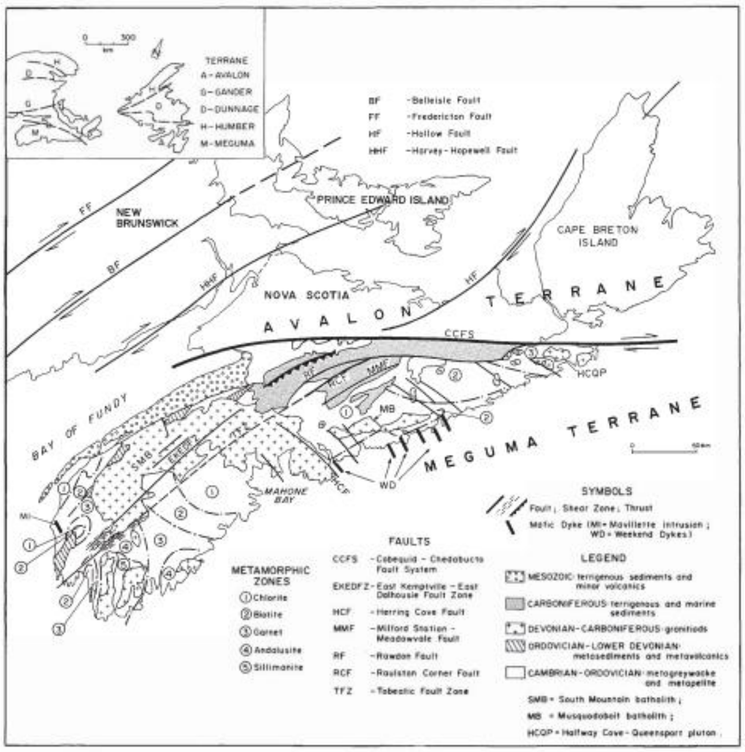


Figure 3. General geological map of the Meguma Terrane showing the geological setting of the South Mountain Batholith (Home et al. 1992)

and is joined to the Avalon Terrane, its northern neighbour, along the Minas Fault Zone. The South Mountain Batholith is located within this Meguma Terrane. The Meguma Terrane includes the pre-granitic rocks from the Cambrian-Ordovician Meguma Group, and the overlying Silurian-Devonian White Rock and Torbrook Formations (Macdonald et al. 1991). The White Rock Formation is composed of psammites of the Goldenville Formation, unconformably overlain by pelites of the Halifax Formation. The Torbrook Formation is mainly composed of mixed volcanic rocks as well as some metasedimentary rocks mixed in. These formations were later deformed and metamorphosed in the Mid to Late Devonian Orogeny (Macdonald et al.

1991). The South Mountain Batholith and other peraluminous granitic intrusions were intruded following this regional deformation. This would place their age of emplacement at approximately 370 Ma (Reynolds et al., 1987; MacDonald et al. 1991). Figure 3 shows a generalized map of the Meguma Terrane from Home et al. (1992), depicting the specific geologic setting of the South Mountain Batholith in relation to the Meguma Terrane and surrounding bedrock.

2.2 Area of Study

MacDonald et al. (1992) documented an extremely detailed account of the geology of the South Mountain Batholith, and a generalized map of MacDonald's work with Home (1992) is shown in Figure 4. Our specific area of interest is outlined in a red box on the left corner of the map.

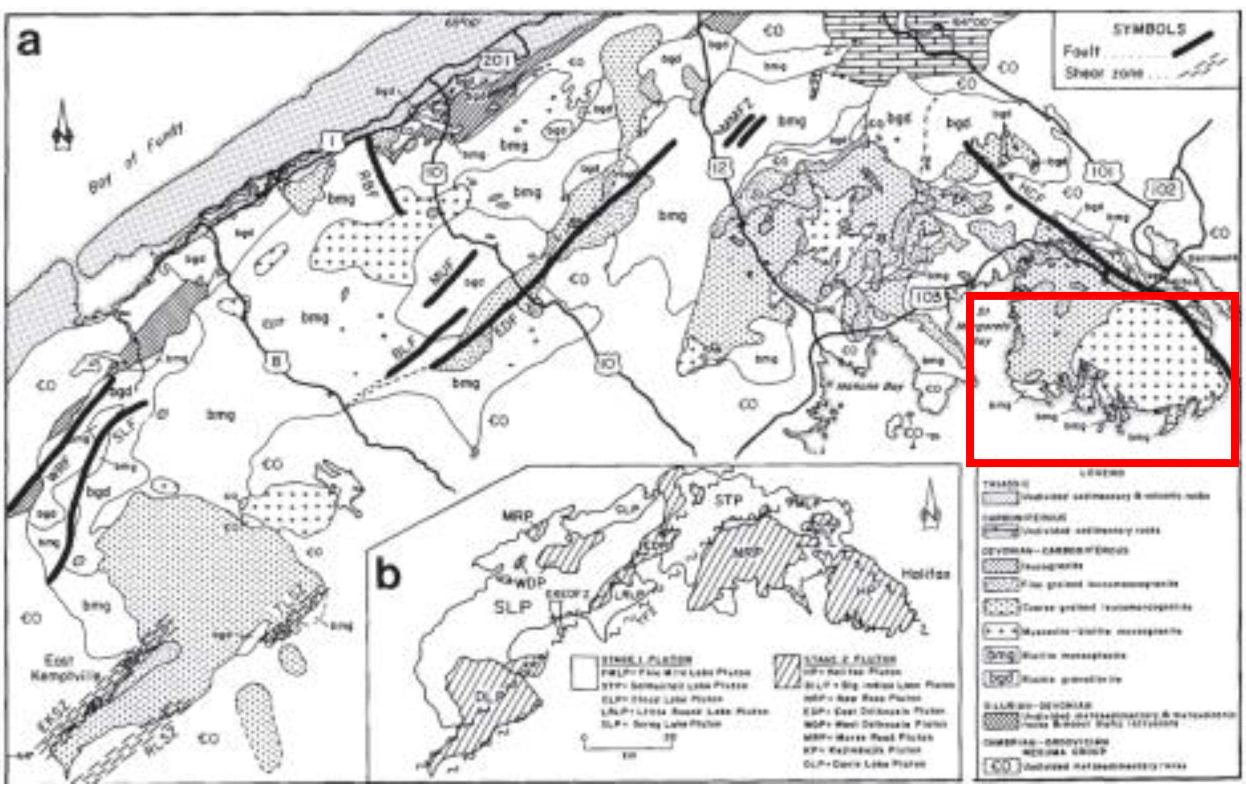


Figure 4. Geologic map of Nova Scotia from Home et al. (1992)), showing the distribution of various lithology units including the South Mountain Batholith.

MacDonald et al. (1992) suggested that the batholith could be subdivided into thirteen different plutons, all of which are their own distinct intrusive event and vary in complexity from singular to composite intrusions. These thirteen plutons can be sub-categorized based on timing of emplacement and lithologies into a Stage 1 pluton and a later Stage 2 pluton, as shown in Figure 4(b). Stage 1 plutons are dominated by mostly granodiorites and monzogranites and the later Stage 2 pluton is dominated mostly by monzogranite and some leucomonzogranite and leucogranites.

The three field sites chosen for this study are: (1) Peggys Cove, (2) Prospect and (3) Bald Rock at Sambro Head. Figure 5 illustrates a simplified magnified version of the map inside the red box from Figure 4 along with the three numbered field sites. These three localities all fall within the biotite monzogranite in the Stage 1 pluton. The biotite monzogranite is generally medium-coarse grained, 10-17% biotite, and contain trace amounts of muscovite and cordierite (Macdonald et al., 1992). Sambro Head (3) was selected as a sample site because of the presence of a mafic intrusion injected into the granite at this outcrop. Prospect (2) and Peggys Cove (1) do not have any clear dyke features however, Prospect (and Peggys Cove to a lesser degree) have large broken up fragments of a mafic material scattered throughout the exposure.

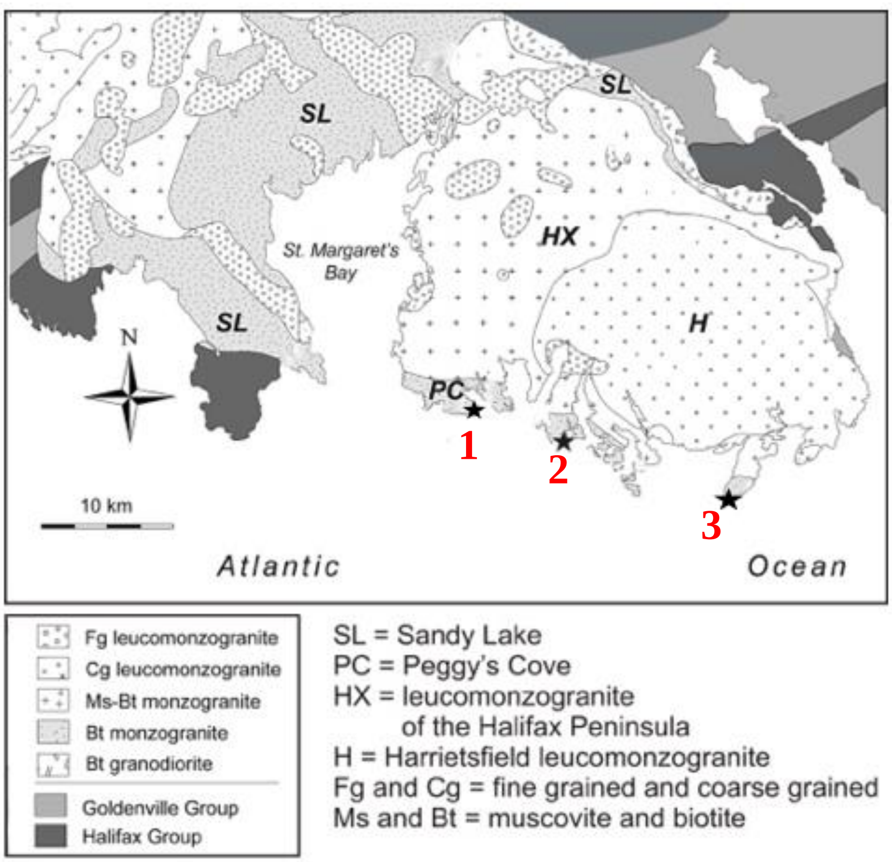


Figure 5. Enlarged map created by Lackey et al. (2012) after Home (1992) depicting the South Mountain Batholith lithologies. The stars and numbers depict our three study areas, along the south shore of Nova Scotia. The three localities are (1) Peggys Cove, (2) Prospect, and (3) Sambro Head

2.3 Previous Evidence of Magma Mixing and Intrusions

2.3.1 Port Mouton Pluton

Hybridization has been documented in other Late Devonian peraluminous granitoid bodies in Nova Scotia. Tate et al. (1997) and later Clarke et al. (2000) conducted studies on the Port Mouton Pluton and observed clear evidence for mingling and mixing of the pluton with mafic magmas. They found that two felsic plutons, of similar age to the Halifax pluton, contained three synplutonic mafic-intermediate intrusions that record progressive stages of hybridisation. Figure 6 is an image of the mafic intrusions present at Port Mouton (Clark et al. (2000)).

Figure 6. Photo of mafic injections and hybridisation in the Port Mouton Pluton, from Clark et al. (2000)

The only direct evidence of mafic intrusions in our study is the dyke located at Sambro Head. However, Port Mouton is only approximately 150 km away from the Halifax Pluton. Because of their proximity and relative age, it is likely that similar hybridization processes occurred throughout both plutons.

2.3.2 Weekend Dykes - Sambro Island

Ruffman & Greenough (1989) also discovered a group of mafic dykes along the eastern shore of Nova Scotia, ranging from Halifax to Country Harbour., just east of Sambro Head. These dykes however were generally vertical, with an abundance of carbonate, apatite, and hydrous mafic minerals. Abundant gneissic and plutonic xenoliths were also found within half of the known dykes. The weekend dykes clearly cut across the granite with no indication of any potential mixing zones, therefore these mafic intrusions are younger than the granite. The dyke observed at Sambro Head has observable mingling of the granite and the mafic elements on the contacts and there are fragments of the dyke within the granite. This indicates a time difference of emplacement between this dyke at Sambro Head and the weekend dykes further east. These features coupled with the fact that the Sambro Head dyke does not contain any evidence of carbonate, or apatite leads the belief that these dykes are dissimilar. To demonstrate these differences further, Figure 7(a) and Figure 7(b) show photos of the ‘Devil’s Staircase’ dyke at Sambro Island, and the dyke observed in our field area, Sambro Head.

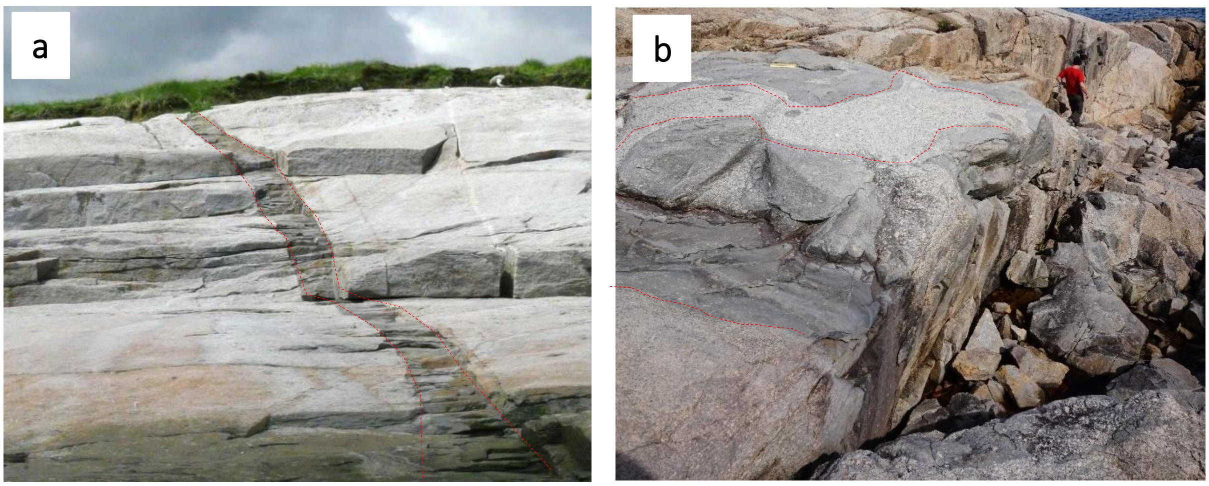


Figure 7. (a) ‘Devil’s Staircase’ dyke cross cutting the granite (Maybank, 2010) versus (b) the globular, irregular outline of the dyke feature at Bald Rock, Sambro Head

CHAPTER 3: METHODOLOGY

3.1 Introduction

A number of specific techniques were used in this study to fully quantify and understand the petrology of the Prospect, Sambro Head, and Peggys Cove granites. This included specific field excursions in order to collect samples from the specific sites of interest. Thin sections were created from the samples collected and petrographic observations were carried out on these thin sections. The electron microprobe was used, specifically to create point analysis, backscattered electron images, and x-ray maps, to fully analysis these thin sections to a microscopic level.

3.2 Field Methods

3.2.1 Sampling

Samples from Prospect and Peggys Cove had been previously collected (Wongus, 2013) and were accessible for use in this study. Fresh samples were collected from the dyke intrusion at Sambro Head. The specific area taken for hand samples were selected based off several factors: their level of weathering (samples were preferentially chosen with less surficial weathering), the localities specific interaction with the dyke, and their level of accessibility. Evident veins of other material were purposefully avoided in order to keep the samples as clear of contamination as possible.

Seven samples were taken in total from Sambro Head. Three (Sample 2, 6, & 7) were sampled from within the edge of the dyke feature shown in Figure 8(a) but without crossing the contact into the granite. Sample 1 & 5 were taken at the perceived center of the dyke. Sample 3 was taken of the granite directly next to the dyke intrusion, with a contact also present within this sample. Sample 4 was taken within a mixing zone where the granite appears to have intruded into the partial liquid melt of the dyke, as shown in the red box in Figure 8(b). Figure 9 depicts a simplified hand drawn schematic of the dyke and the granite illustrating in red where we sampled for reference.

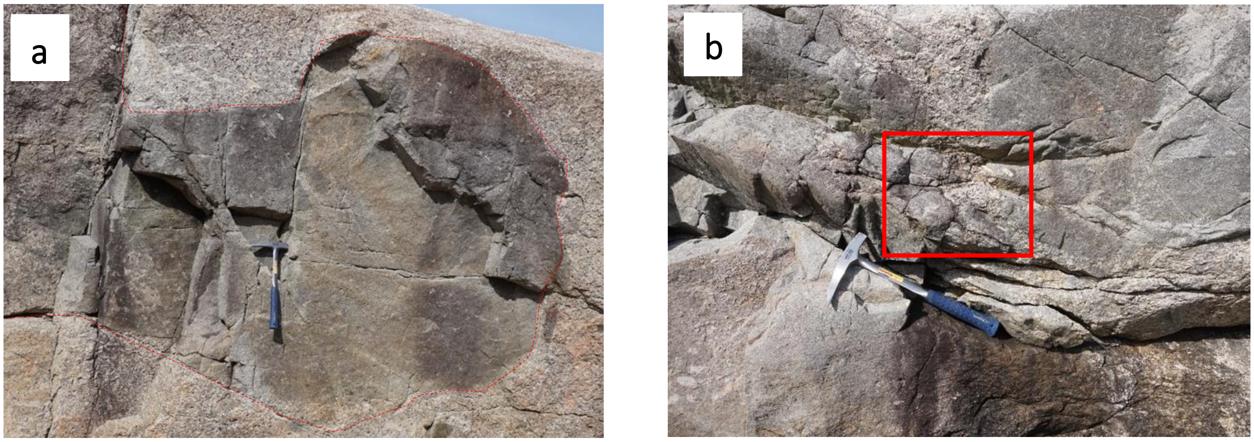


Figure 8. (b) Outline of dyke feature present at Sambro Head and (b) photo of granite mingling with the mafic dyke contact

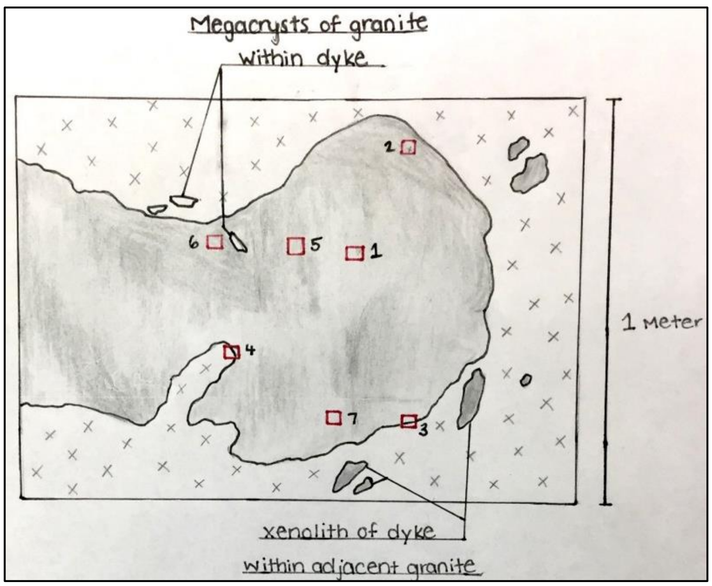


Figure 9. Hand drawn schematic of the mafic dyke at Sambro Head with specific sample areas (red boxes)

3.3 Petrology

The seven rock samples from Sambro Head were cut with a 10” rock saw into ‘bread-like’ slices of approximately 2-3cm width. These were analyzed for megacrysts and other crystals of interest. Measurements and images of all the slabs were taken, as well as measurements and images of the hand specimens.

The final seven polished thin sections (Figure 10) were chosen from the hand samples based off the presence of features of interest, such as megacrysts or boundaries. Samples were taken directly from the center of the samples to avoid anomalies created from weathering at the edges.

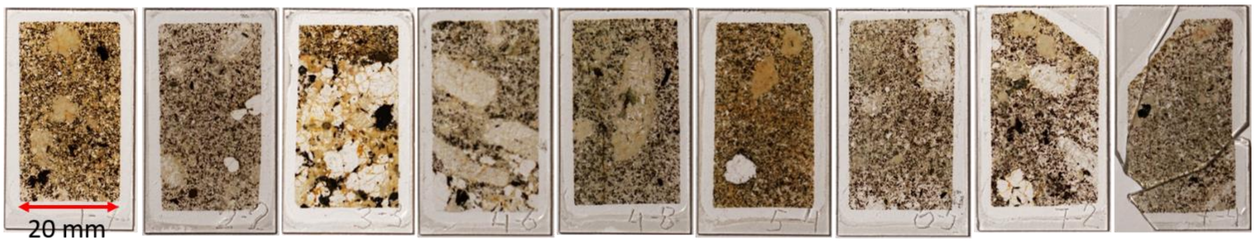


Figure 10. Series of images showing the seven thin sections created from the hand samples in Sambro Head. They are polished thin sections, all 20 mm by 38 mm. They show a multitude of different fabrics and textures from the dyke and granite.

Previously collected polished and unpolished thin sections created by Derek Wongus (2013) were also used as comparison to the thin sections created from Sambro Head. Wongus collected his samples from Peggys Cove and Prospect, choosing them based on the presence of complete sub-euhedral megacrysts falling within the field of view of the thin section. He also noted that those with surrounding matrix were more favourable (Wongus, 2013).

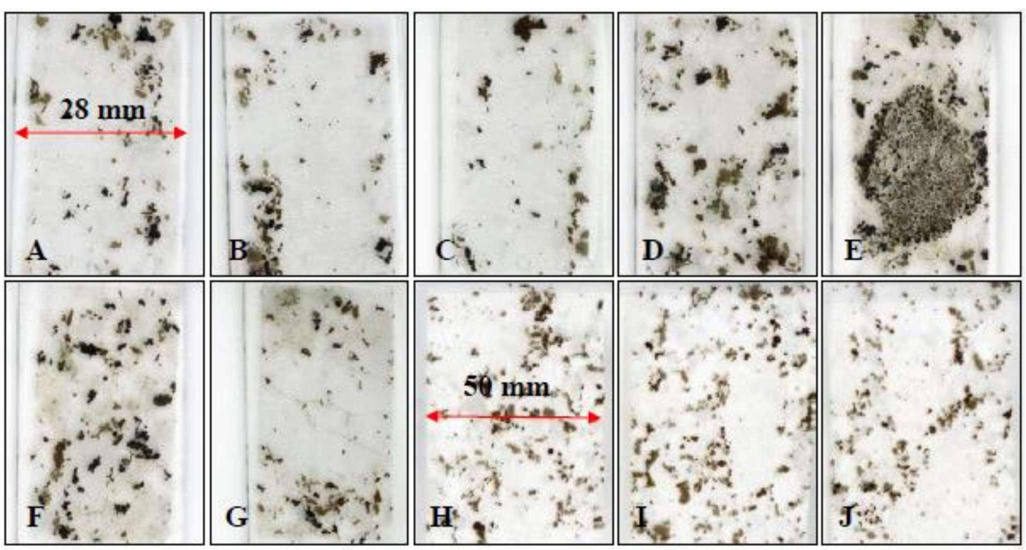


Figure 11. Photos of the cut thin sections from Peggys Cove and Prospect (Wongus (2013)). They are polished and unpolished thin sections, mostly showing large euhedral K-feldspar megacrysts (white crystals). The dimensions from A to G are 27 mm by 48 mm and the thin sections H to J are 50 mm by 75 mm.

3.3.1 Microscopy Images

We used a digital camera set up to a Nikon ECLIPSE 50iPOL microscope to take the microscopy images. For the megacrysts that were larger than the field of view, we took multiple overlapping images then stitched them together afterwards in order to create a complete image of the megacryst in the thin section. Each overlapping image was taken with special consideration to its relation with the previous image, in order to garner a suitable amount of overlap and guarantee the most accurate panorama image possible.

3.4 PTGui

3.4.1 Operation of PTGui

PTGui is a panoramic image stitching software program. Images taken in sequence or adjacent to one another can be stitched together to create a complete, larger image. The images need to align properly in the program, which identifies patterns by specific light and pixel identifications.

3.4.2 Application of PTGui

This stitching software and the Nikon ECLIPSE 50iPOL photos were used concurrently in order to create a full image of the K-feldspar megacrysts present in the thin sections from Sambro Head, Prospect, and Peggys Cove. A minimum of twelve to as many as twenty photos were used to stitch together to create these panoramas. In particular, the panoramas were used to encapsulate the large K-feldspar megacrysts that were frequent in most of the samples.

3.5 Electron Microprobe

3.5.1 Operation of electron microprobe

The JEOL JXA-8200 Electron Probe Micro-analyser (EMPA), 'SuperProbe' is the property of Dalhousie University and a part of the Robert M. MacKay Electron Microprobe Lab. The EMPA has five WD-spectrometers (WDS) with an additional energy-dispersive X-ray spectrometer (EDS). The microprobe functions by shooting high-energy electrons at a pre-chosen sample target to emit specific X-rays. The EDS is what detects the resulting energies from the bombardment of the electrons while the WDS distinguishes the particular wavelengths of interest. These X-rays are subsequently collected and measured against specific standards of known compositions (JEOL, 2012). The microprobe is able to analyze features at magnifications up to 300,000x, making it ideal for analyzing small microscopic textures. The microprobe is able to detect a range of a few parts per million to several hundred ppm of most elements (Be-U) and twenty-one elements simultaneously (JEOL, 2012). However, for this research, the particular oxides of interest were SiO_2, Al_2O_3, Na_2O, K_2O, CaO, BaO, and SrO.

3.5.2 Point analyses

The WD-spectrometer emits the electron beam, which bombards the sample and area of interest and causes it to emit x-rays at wavelengths characteristic to the elements being analyzed. This enables us to determine the abundances of elements present to within a very small sample volume (typically 10-30 cubic micrometers). This is useful in order to determine particular compositions of crystals in distinctive areas of our sampling area.

These point analyses can be conducted in a line across a particular sample, in order to give compositional changes across a distance. This is useful in determining compositional changes from the core to rim of particular crystals or across particular boundaries or contacts.

We conducted multiple point analyses on our thin sections, on the K-feldspar megacrysts and plagioclase crystals. We performed line scans across the plagioclase and K-feldspar, especially in areas with high oscillatory zoning, in order to get a quantitative analysis of the composition of these crystals as they were growing.

3.5.3 Backscattered electron (BSE) imaging

Backscattered electron imagining creates a compositional image generated from the electro-beam interacting with the sample. The heavy atoms with a high atomic number are scattered more strongly than the lighter ones. Therefore, the heavier atoms will scatter a higher concentration of electrons back, and appear brighter on the image, while the lighter atoms will appear darker. The BSE is useful as images can be obtained nearly instantly, depending on scan rate, and at any magnification within the instrument range. Thus, these images are a quick and easy means of determining the mutual textural relationship and compositions of your samples.

We took multiple BSE images for this study, generally focusing on the megacrysts of interest, such as the plagioclase and the K-feldspars. The images were taken on thin sections from all three sample areas – Peggys Cove, Prospect, and Sambro Head. If the megacrysts of interest were too large for the smallest magnification in the field of view, multiple BSE images of the top and bottom of the crystal were taken instead, making sure to maintain some overlap.

3.5.4 X-Ray Mapping

Element maps of X-ray maps are images that show the spatial distribution of elements within a sample. They are created by progressively blasting an electron beam point by point over an area of interest. The chosen beam size determines the resolution and the response of the chemical elements in your sample is determined by how long the beam dwells on each point. Element maps are extremely useful in displaying particular element distributions to give a textural context to a crystal, particular for showing compositional zonation.

We created multiple element maps of different beam sizes and dwell times. We chose crystals from the three sample locations and each X-ray map was conducted using varying pixel sizes and run times. A beam current of 1.00×10^{-8} A was used consistently for each sample.

3.5.5 Triplot

To plot the points on to the ternary diagram, first the chemical analysis of the rock is recalculated to molecular proportions by dividing the molecular weight of each oxide constituent by the molecular weight of that oxide and then normalize them so that they add up to 1. These points were plotted automatically from excel into a tertiary diagram using the Triplot software.

CHAPTER 4: RESULTS

4.1 Introduction

The samples collected and the techniques that we utilized in the data collection for Sambro Head were selected specifically to distinguish compositional changes within the phase of the magma of the Halifax Pluton. In order to suggest more than one type of magma presence to show hybridization occurred in this section, we must give supporting evidence. We utilized observations from hand samples in Sambro Head, Peggys Cove, and Prospect to pick up specific textures at an eye level. We created thin sections in order to make petrographic observations on the patterns and textures of the crystals, and we utilized Dalhousie University's microprobe equipment in order to provide supporting microscopic data as another potential tool for interpreting results. For the complete data set and images, refer to the Appendix.

Derek Wongus (2013) interpreted hand samples taken from Peggys Cove and Prospect and determined that they were biotite monzogranite, paralleling the work done by MacDonald et al. (1992) and MacDonald et al. (2001). Wongus (2013) interpreted the modal proportions to be 25-35% K-feldspar, 20-45% quartz, 15-25% plagioclase, 10-17% biotite. The observational results from the granite at Sambro Head also determined the granite to be of the same composition as Peggys Cove and Prospect, a biotite monzogranite. The granite is of a porphyritic texture, with large K-feldspar megacrysts and the plagioclase being much smaller, and a part of the groundmass.

The composition of Sambro Head is similar to Prospect, with similar shaped euhedral K-feldspar crystals. The grain size in Sambro Head is similar to the sizes in Prospect, but bigger overall than the crystals at Peggys Cove. Sambro Head exhibits a more 'pinkish' hue to the rocks at the other localities, likely due to the higher amounts of visible K-feldspar megacrysts and the overall size of these megacrysts.

4.2 Bald Rock, Sambro Head

4.2.1 Field Observations

The granite at Sambro head is similar in colour to the Prospect granites. It is white and brown with grey mottling. The megacrysts are very well defined, with large pink-grey euhedral

K-feldspar megacrysts throughout the granite. The white elements of the granite are the plagioclase and the smaller black specks are the biotite, present in the dyke and the granite. Quartz crystals are present in dark grey blobs.

The dyke feature present at Sambro Head has irregular boundaries, some boundaries being very sharp cut while in other areas the granite is intermingling with the mafic intrusion. Several smaller mafic enclaves can be seen peeled away from the main dyke i.e. there has been partial mixing of the mafic material into the granitic host. The presence of a reaction selvage of biotite also suggests that the dyke was not in equilibrium with the host granitic magma. Figure 12(a) depicts the irregular dyke contact with the granite and Figure 12(b) the mixing zone of the dyke and granite as well as large granitic xenocrysts entrapped within the dyke.

Refer to Appendix A for further field photographs.

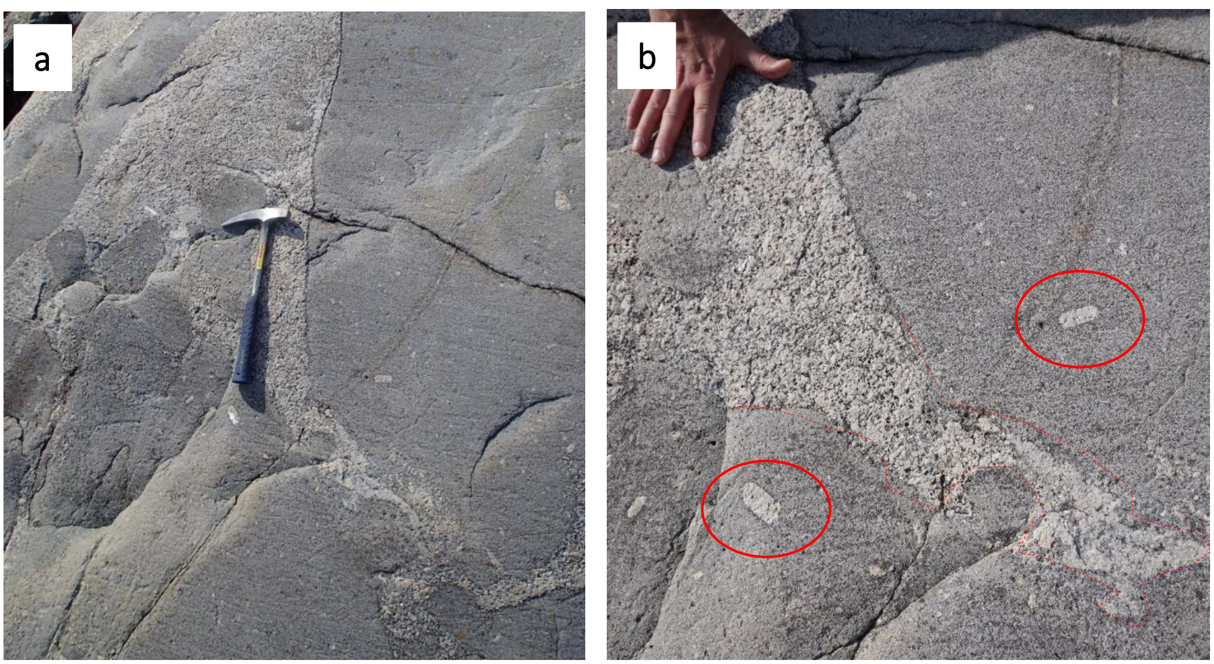


Figure 12. (a) Mafic dyke boundary and granite section, Sambro Head. Smaller mafic enclaves of similar composition surround the dyke (b) Enlarged photo of the mixing zone between the dyke and the granite as well as K-feldspar megacrysts within the dyke.

4.2.2 Mineral and Matrix Descriptions

The K-feldspar crystals in Sambro Head are euhedral and have an average length of 2-4cm and width of 0.5-1.5cm. They have a pink-grey hue, similar to Prospect but a little darker than Peggys Cove. Carlsbad twinning can be visible in some of the larger K-feldspar crystals under good light. The plagioclase in the Sambro Head granites is largely a part of the phaneritic groundmass. They are generally rounded and a white-grey colouring, distinguishable from the darker grey colour of the quartz. The matrix is largely a tonalitic texture, made up predominantly of biotite and quartz. The quartz is largely in small dark grey globular shape, and the biotite crystals are black, long and crystal-shaped. The biotite crystals are situated throughout the granite matrix; however tend to cluster with greater frequency around the larger K-feldspar megacrysts.

4.2.3 Distinguishing Features

The dyke is a much darker colour than the surrounding granite. It has a coarser texture at the center than at the edges. It has irregular boundaries, part of the contact is sharp and other parts directly mix with the granites. The matrix of the dyke is mainly tonalitic, predominantly made of biotite and quartz. Figure 13 shows four hand samples taken from the dyke at Sambro Head. Figure 13(a) is sampled at the edge of the dyke and Figure 13(c) was sampled in the mixing zone of the dyke and the granite. Figure 13(b) was sampled from a sharp contact between the dyke and the granite that hasn`t experienced magma mingling. There are many large K-feldspar xenocrysts from the granite trapped within the dyke at the mixing zone, and inside the dyke itself. However, Figure 13(d) indicates that the amount of K-feldspar megacrysts decreases drastically to almost none as you progress towards the center of the dyke, suggesting the dyke did not mix extremely thoroughly with the granite.

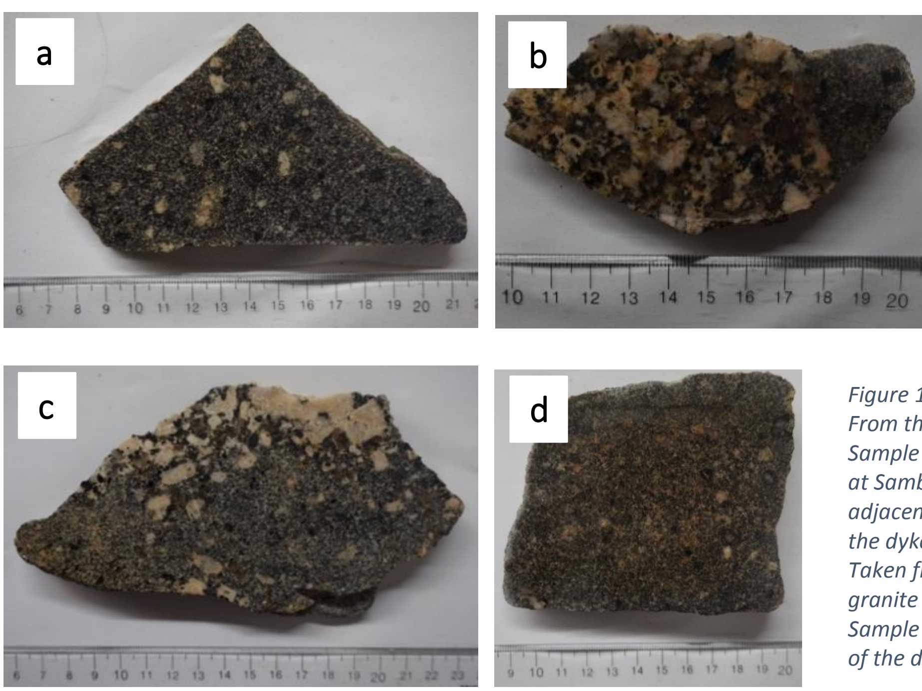


Figure 13. (a) Sample 2-5. From the edge of the dyke. (b) Sample 3-3. From the granite at Sambro Head directly adjacent to the contact with the dyke. (c) Sample 4-5. Taken from mixing zone of the granite and the dyke. (d) Sample 1-7. From the center of the dyke

4.3 Prospect

4.3.1 Field Observations

The Prospect section of the Halifax pluton is a white and brown coloured granite with grey mottling and overall was a lighter hue than the Peggys Cove section. The K-feldspar megacrysts within the granite are much more euhedral and defined than at Peggys Cove, and the amount of intact megacrysts seemed to be present at a greater frequency. They appear to cluster and streak together suggesting movement and a flow pattern. There were no apatite or pegmatite veins observed at this locality, and Prospect appeared to be less weathered than the granite observed at Peggys Cove.

An anomalous feature at Prospect are dark, irregular mafic enclaves spaced throughout the granite; photos are shown in Figure 14. They average from around 30-75cm in diameter and are mostly circular or globular in shape. Some have sharp boundaries while others have xenocrysts of the granite within them. A particular feature of interset is a k-feldpsar megacryst that is cross cutting the boundary of the mafic fragment (Figure 14(b)), indicating these enclaves were partially liquid as they intruded into the granite. In some of the mafic enclaves the granite has altogether intruded and mixed into the borders of the mafic material (seen along the left margin of Figure 14(a)). There were some autoliths and xenoliths found at Prospect however, they were dissimilar in shape and size to the mafic enclaves at Prospect.

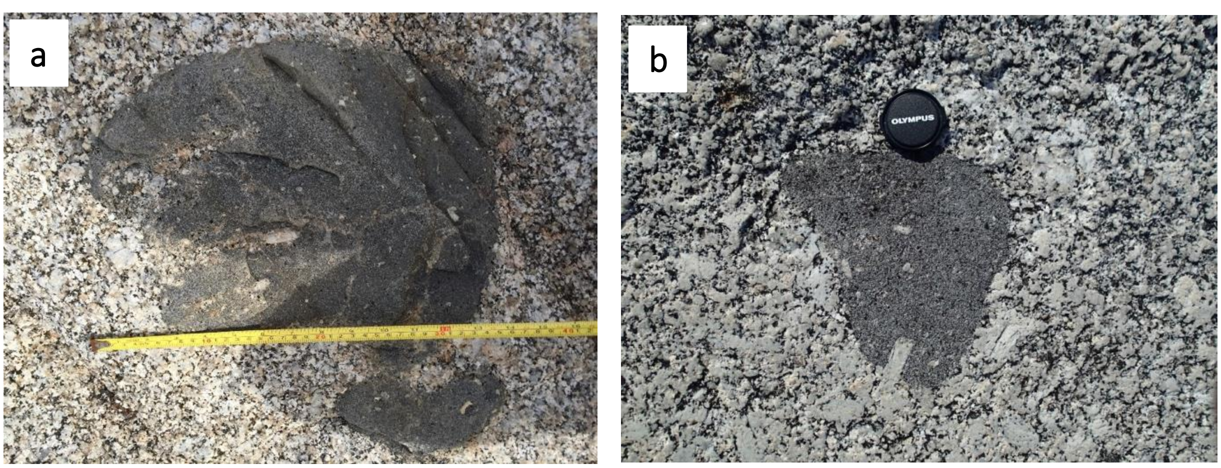


Figure 14. Mafic fragments observed at Prospect. (a) Granite intruding into and mingling with the mafic enclave (b) A K-feldspar megacrysts directly cross cutting the mafic material boundary

4.3.2 Mineral and Matrix Descriptions

The K-feldspar megacrysts at Prospect are very euhedral in shape and averaged in size from 2.4-4 cm in length and 0.5-1.5 cm in width. Under good light conditions, twinning is visible in some of the megacrysts without the use of a hand lens. The plagioclase crystals were predominantly within the groundmass, and under the hand lens showed a massive texture. They are a dark brown in the hand sample. The biotite grew predominantly beside the K-feldspar crystals within the groundmass. The biotite grains at Prospect were largely clumped together and arranged throughout the matrix. Some biotite crystals were observed within the megacrysts as inclusions, but were found most frequently along the margins of the crystals.

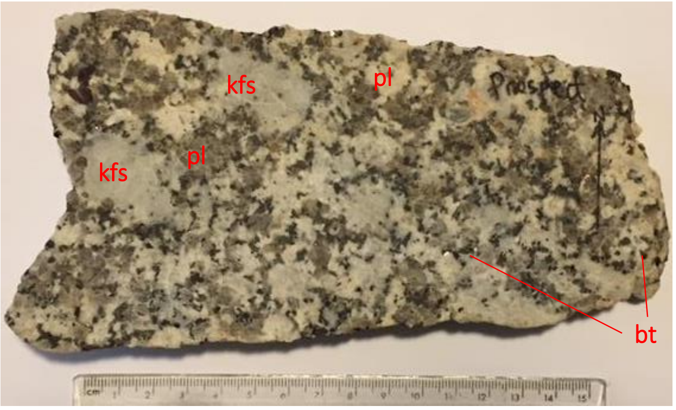


Figure 15. Large hand sample from Prospect. K-feldspar megacrysts are apparent.

4.4 Peggys Cove

4.4.1 Field Observations

The Peggys Cove section of the Halifax Pluton is less weathered than the Prospect section. Peggys cove has an intermediate colour scheme and overall a darker hue than Prospect and Sambro Head. Peggys Cove had a higher abundance of autoliths and xenoliths throughout the granite than at Sambro Head and Prospect, approximately 2-4% of the granite. The xenoliths tended to be of a gneissic texture, with visible striations. They were mostly very small, around 2-4cm in size. Figure 16 depicts one of these xenoliths.

Other distinguishing features included apatite and pegmatite veins that frequently crosscut the granite in several localities.

Figure 16. Weakly layered xenolith within the Peggys Cove granite section. Source (Clarke et al., 2000)

4.4.2 Mineral and Matrix Descriptions

Figure 17 shows a hand sample from Peggys Cove. The K-feldspar in Peggys Cove was of various sizes throughout the granite, ranging from 2-4cm in diameter. The crystals were largely globular in shape, and were smaller on average than the K-feldspar crystals found in Prospect and Sambro Head. The biotite crystals were commonly found in clumps and forming small enclaves within the matrix. The plagioclase was various shades of grey in Peggys Cove, with the majority of crystals being smoky grey. The texture of the plagioclase crystals under hand sample is massive.

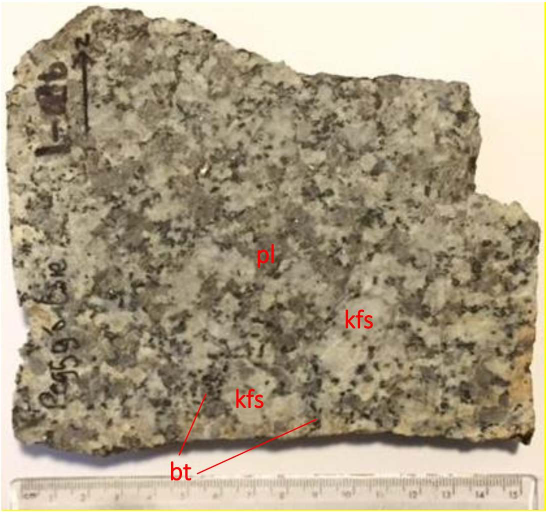


Figure 17. Large hand sample from Peggys Cove. K-feldspar megacrysts are less euhedral, and more globular.

4.5 Petrography

4.5.1 Sambro Head

Outlined below are descriptions and petrographic photos of a select number of crystals within the thin sections from Sambro Head. Full photos of the thin sections and additional petrographic photos are found in the Appendix A.

4.5.1.1 Plagioclase

The plagioclase crystals under the microscope show strong resorption features. They are largely irregular in shape, and changes in composition can be observed from the core to the rim (as shown in Figure 18(a)), indicating a change in the equilibrium or melt composition. Largely the crystals were a dark brown colouring in plane polarized light. In cross-polarized light (Figure 18(b)), they exhibited multi-angle extinction, as well as low birefringence. In some plagioclase cores, especially within crystals growing closer to the edge of the dyke but also observed within plagioclase growing at the center of the dyke (Figure 18(c)), mineral alteration of the plagioclase cores to sericite occurs. Sericite, a fine-grained white mica, forms as an alteration product due to the presence of fluids dewatering from the granite as the dyke intruded.

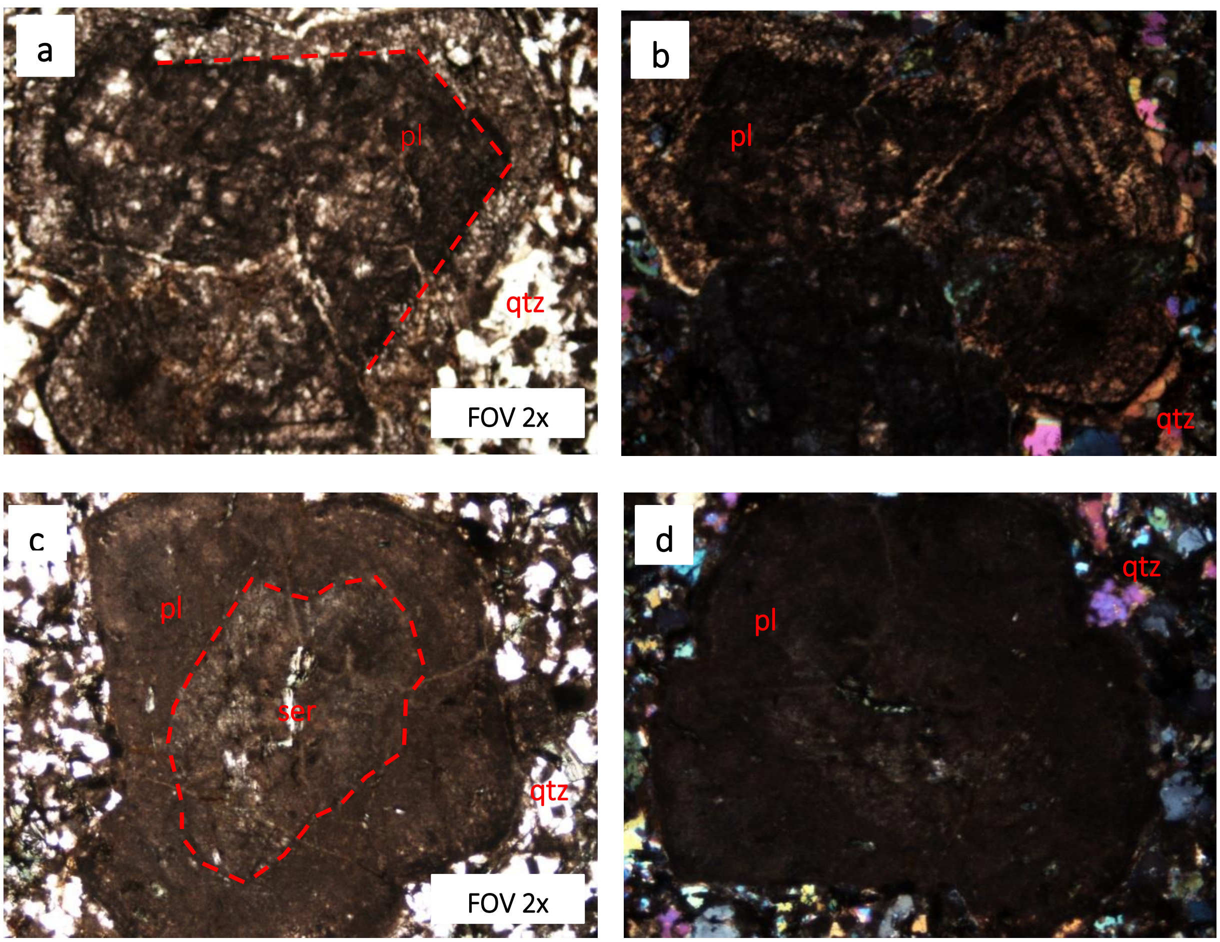


Figure 18. Sample 1.7 plagioclase crystal in (a) plane polarized light and (b) cross-polarized light and Sample 5-4 plagioclase crystal in (c) plane polarized light and (d) cross-polarized light. Sample taken approximately at the center of the mafic dyke.

4.5.1.2 K-feldspar

In plane polarized light (Figure 19(a), (c)), the K-feldspars were a white, translucent colour and mostly very irregular in shape. Few of the crystals were nicely euhedral in shape. In cross-polarized light (Figure 19(b), (d)), they exhibited Carlsbad twinning as well as medium birefringence. They have brown inclusions that make the crystal almost look 'dirty'. The quantity of the K-feldspar crystals decreased the further into the dyke you go; they likely did not survive the mixing process and were all resorbed. Most of the remaining K-feldspar crystals showed signs of disequilibrium and resorption caused by mafic melt surrounding them.

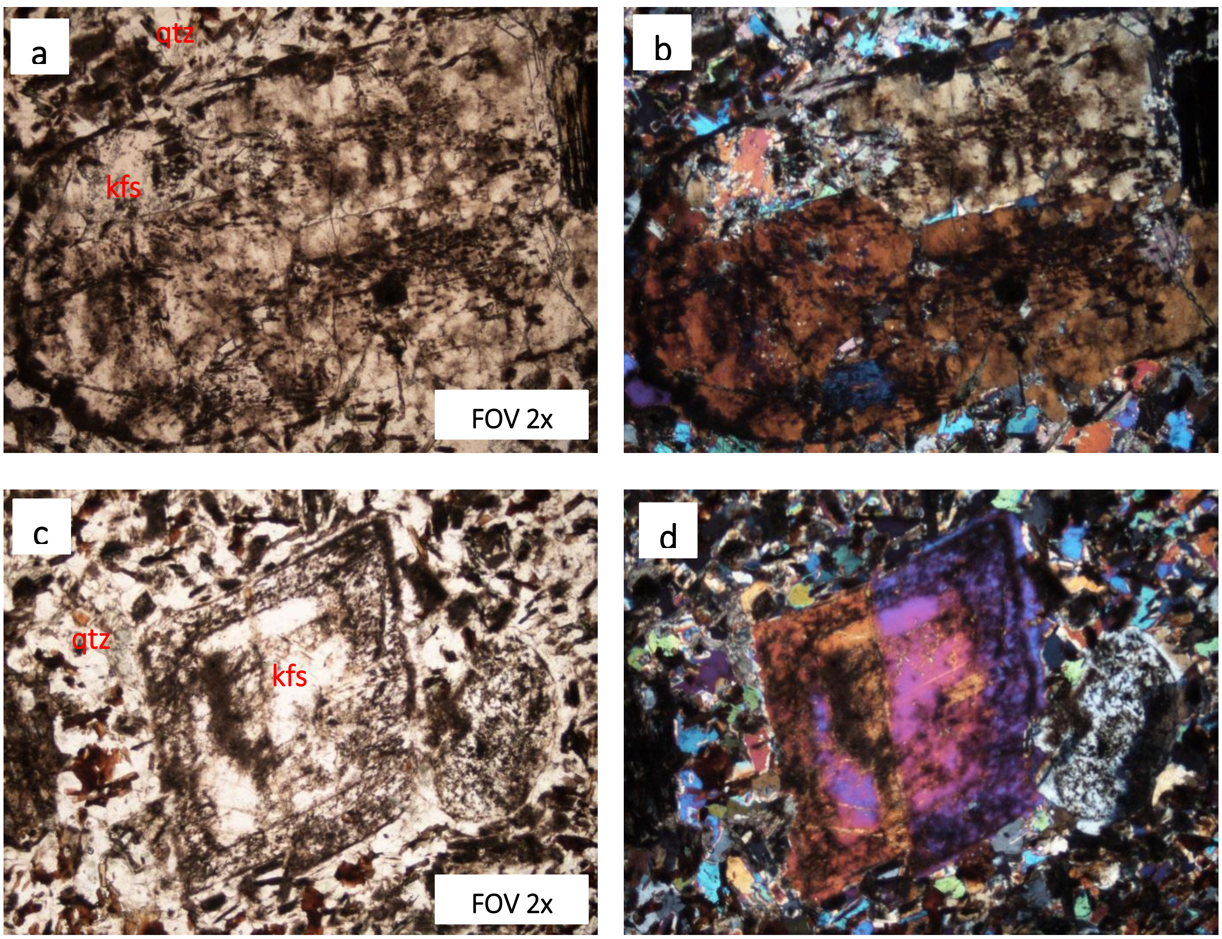


Figure 19. Sample 2-2 K-feldspar crystals in (a)(c) plane polarized light and (b)(d) cross-polarized light. Sample taken approximately at the edge of the mafic dyke. Textures include being highly resorbed, evidence of Carlsbad twinning and strong oscillatory zoning from core to rim. These crystals show signs of disequilibrium with their surroundings and resorption.

Figure 20 and Figure 21 show two panorama images of strongly resorbed K-feldspar megacrysts. Figure 20 is a K-feldspar xenolith from the center of the dyke intrusion. Plagioclase inclusions can be observed around the rim as well as biotite salvage around the outside edges of the xenocrysts. The xenocryst had multiple phases of growth evidenced by the zoning. The initial growth phase was likely within the granite as it shows fewer inclusions than the rim. Figure 21 shows a xenocryst that was trapped within the mixing zone of the dyke and the granite and severely resorbed as a result. This crystal is not in equilibrium with its surroundings as evidenced by the plagioclase mantle around the edges and the severe ‘battered’ appearance of the crystal.

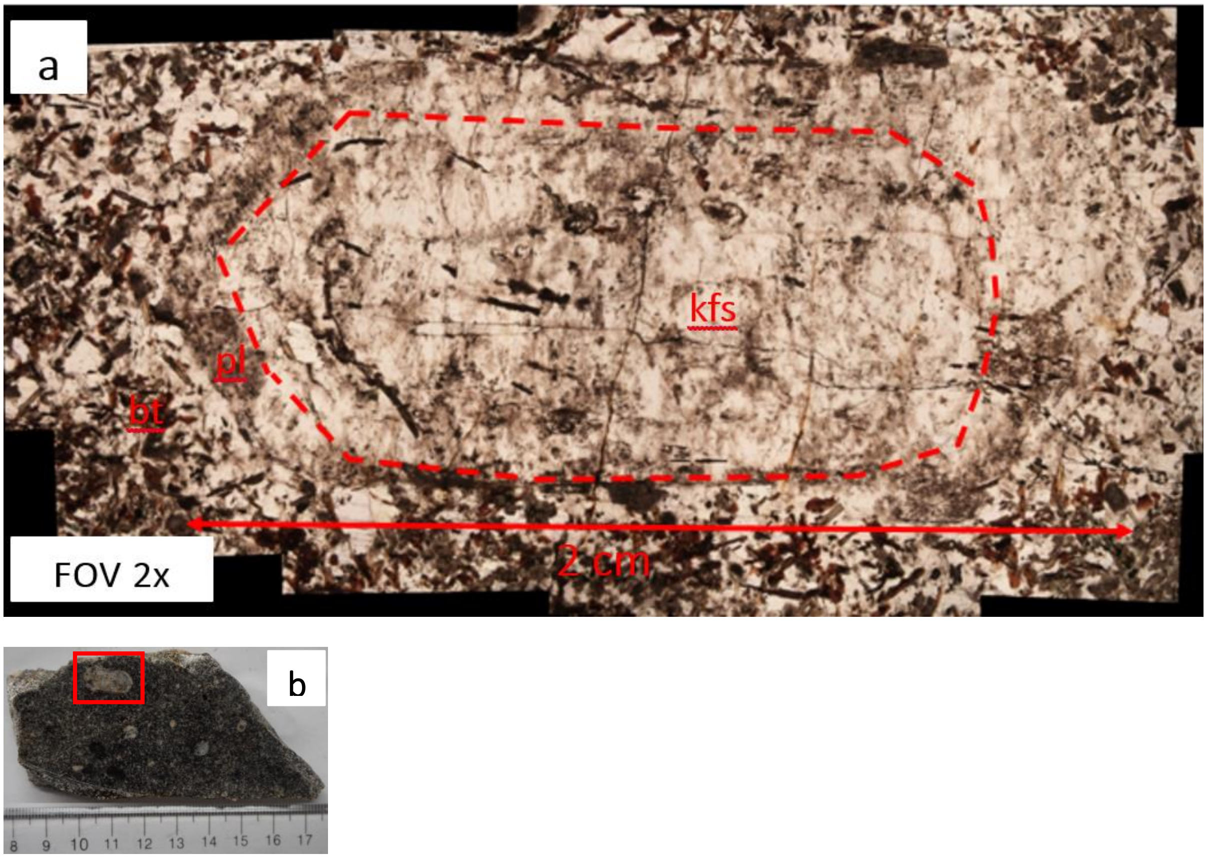


Figure 20. Sample 6-5. (a) Panorama of K-feldspar xenolith in plane polarized light. Sample taken approximately at center of the mafic dyke. Textures include the reaction rim around the crystal with small inclusions of plagioclase growing inside the edges. The blade-like crystals in the center are apatite inclusions. There are also biotite reaction salvage around the edges of this megacryst. (b) The panorama image of the crystal is taken from the megacryst outlined in red in this hand sample.

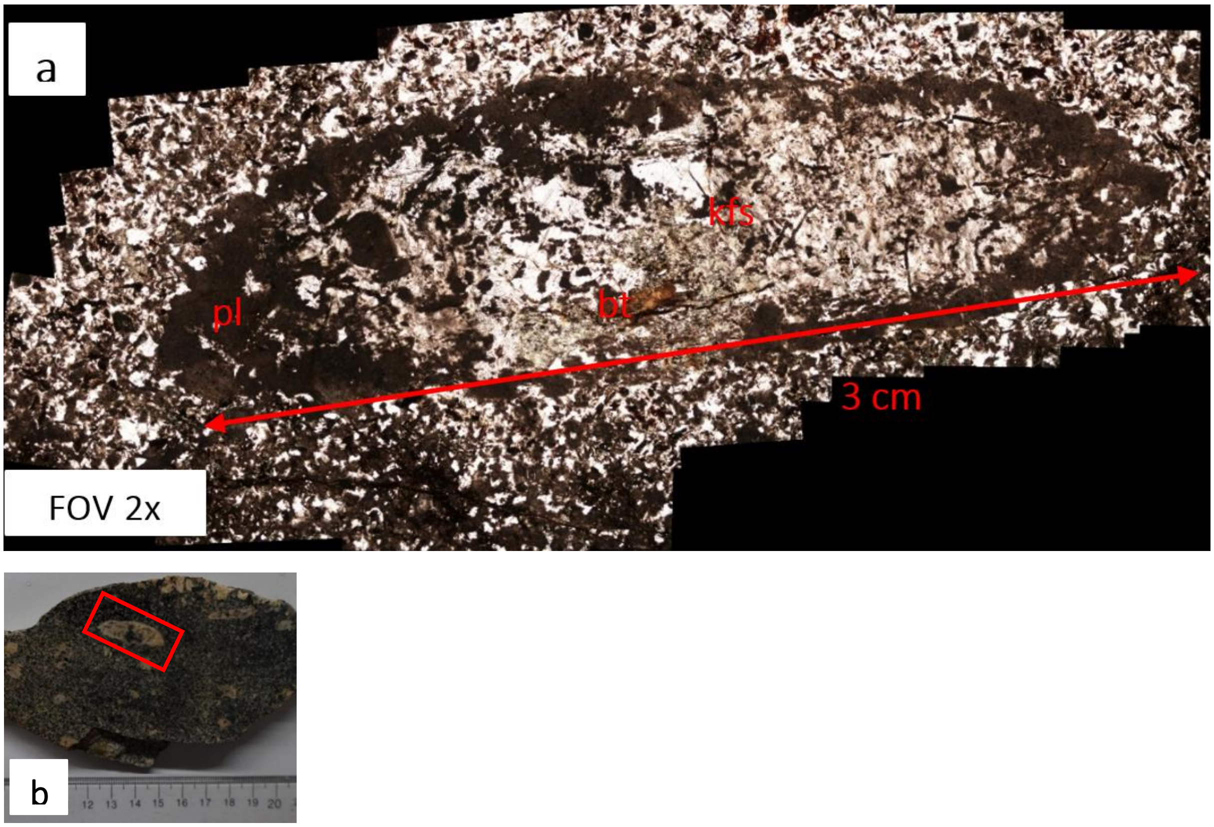


Figure 21. Sample 4-8. (a) Panorama of K-feldspar xenocryst in plane polarized light. Sample taken the mixing zone between the dyke and the granite. Textures include the mantle of plagioclase around the edge of the crystal. There are also biotite reaction salvage around the edges of this megacryst. This megacryst shows signs of disequilibrium – the crystal is extremely resorbed and altered. (b) The panorama of the crystal is from a thin section taken from this hand sample and shows the full scale of this megacryst.

4.5.1.3 Other distinguishing textures

Other distinguishing features within the K-feldspar crystals include blade-like crystals of apatite growing within the largest K-feldspar crystals shown in Figure 22. These K-feldspar crystals contain a reaction rim around the edges indicating they were not in equilibrium during the time that this section of the crystal was growing. The presence of small plagioclase crystals are observed within this reaction rim, as well as clusters of biotite crystals. A close up of these textures are shown in Figure 23.

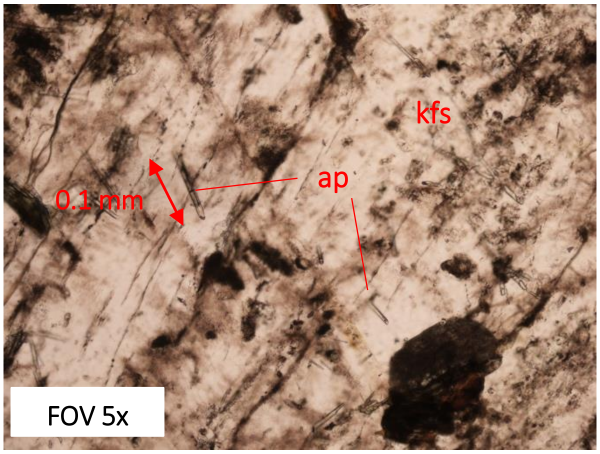


Figure 22. Close up of the Sample 6-5 panorama. Shows apatite crystals that grew within the K-feldspar megacryst

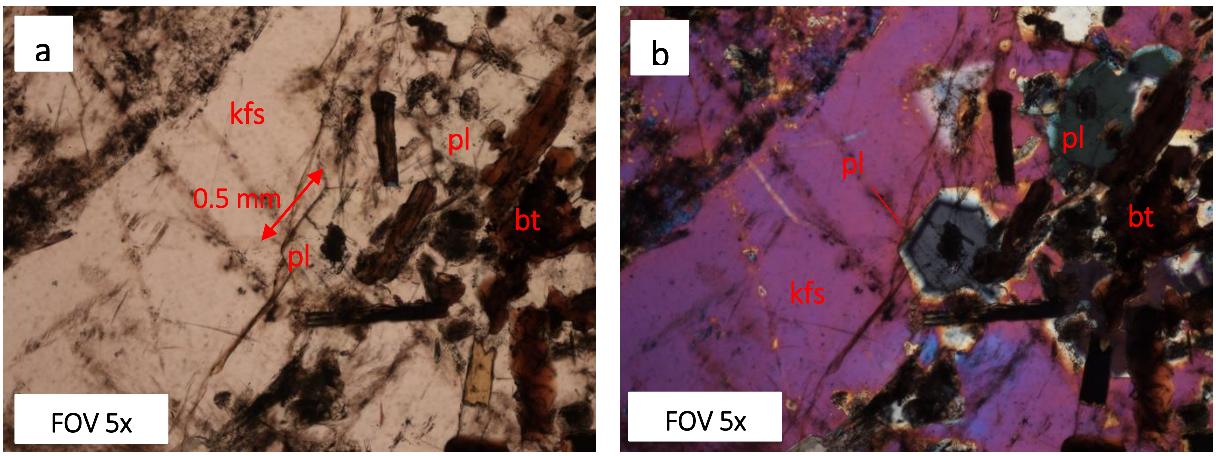


Figure 23. Close up of sample 6-5 panorama (a) Plane polarized light (b) cross-polarized light. Shows growth of plagioclase crystal within the K-feldspar megacryst reaction rim. Reaction salvage of biotite also observable.

4.5.2 Prospect and Peggys Cove

Derek Wongus (2013) conducted full petrographic descriptions of the Prospect and Peggys Cove megacrysts. Figure 24 shows a panorama by Wongus of a K-feldspar megacrysts from Prospect in plane and cross-polarized light.

4.5.2.1 Plagioclase

The plagioclase crystals were much more discreet compared to the K-feldspar megacrysts. It forms in two types: inclusion within the K-feldspar and primary growth. The inclusion type textures have a zoned edge with a sericite alteration at the core (Wongus, 2013). This pattern is identical to the ones in the altered plagioclase crystals found at Prospect. The megacrysts at Peggys Cove show stronger resorption features than the Prospect and are much less euhedral. Several inclusions of biotite and plagioclase form crystal boundaries along the megacrysts edge.

4.5.2.2 K-feldspar

The K-feldspar megacrysts from Prospect and Peggys have as a ‘dirty’ white colour in plane polarized light. The megacrysts, as shown in Figure 24, show various zonation textures and Carlsbad Twinning. Several inclusions of biotite and plagioclase form crystal boundaries along the megacrysts edge. The megacrysts at Peggys Cove show stronger resorption features than Prospect and are much less euhedral. Both megacrysts show evidence of zoning.

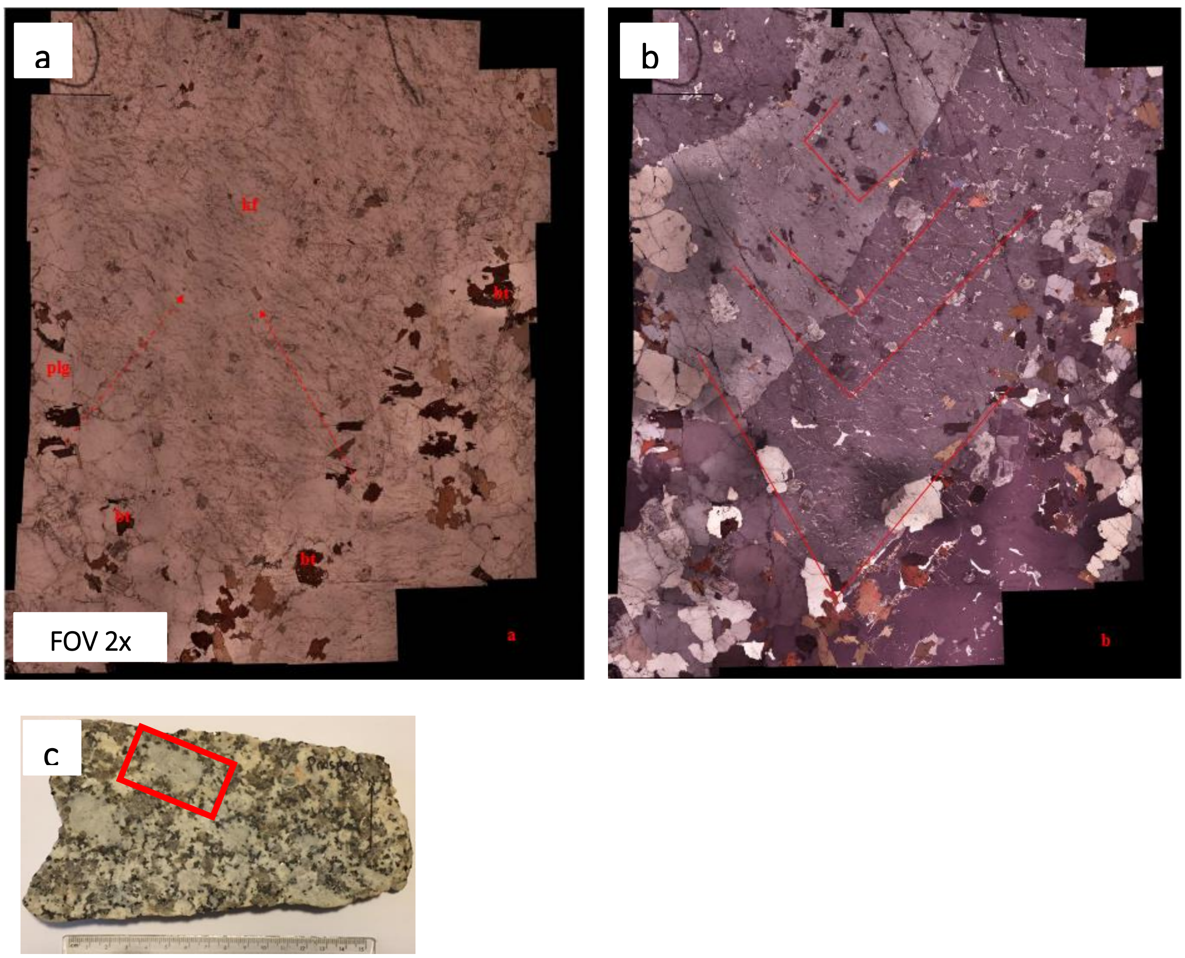


Figure 24. Panorama photos of a Prospect K-feldspar megacrysts. Taken by Wongus (2013). (a) Plane-polarized light (b) Cross-polarized light. (c) The hand sample from where this megacryst came from.

4.6 Electron Microprobe Analyses

The scanning electron microscope (SEM) was used to take back-scattered electron (BSE) images of specific crystals of interest throughout the samples. The WD-Spectrometer took several individual point scans and line scans across zones of interest. The individual points were represented on a ternary diagram and the line scan data was graphically represented using excel. X-ray maps were also created at each locality. Refer to the Appendix B for the complete list of data and graphs created using the SEM. The K-feldspar megacrysts and the plagioclase crystals were specifically targeted for microprobe analysis in this study. The results of the textures found in these crystals are documented at each locality below.

4.6.1 K-feldspar Textures

4.6.1.1 Micrographs

Sambro Head

We took a BSE image of K-feldspar megacrysts within the mixing zone of the granite and the dyke. There were little to no K-feldspar megacrysts within the centre of the dyke. Figure 25(a) is an image of the edge of a K-feldspar crystal that was trapped within the mixing zone of the dyke and the granite. The edge of the K-feldspar megacrysts shows extreme resorption features; this crystal was not in equilibrium as the rim was growing. There are multiple intrusions of plagioclase crystals within the megacrysts. Figure 25(b) shows an enlarged micrograph of one such plagioclase intrusion.

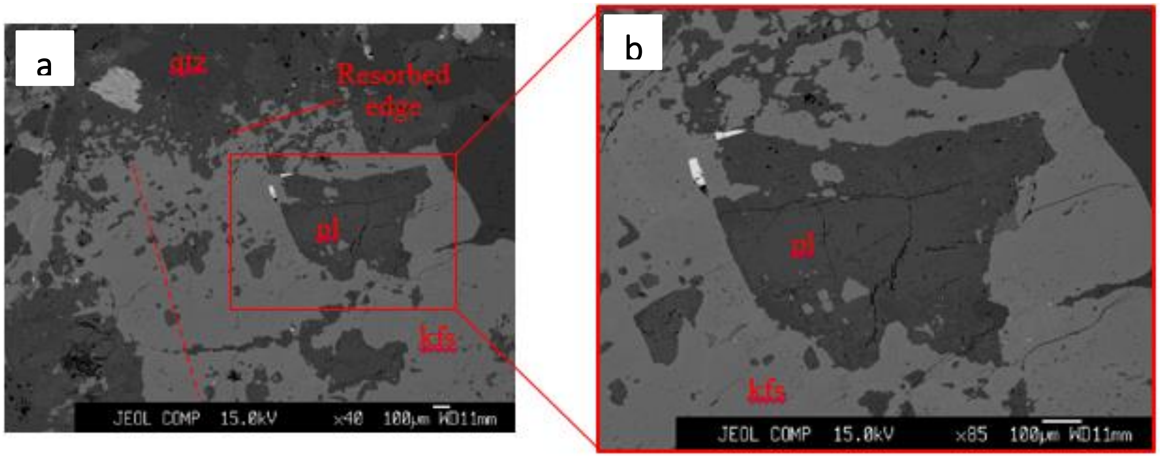


Figure 25. BSE image of Sample 4-6. (a) Shows K-feldspar crystal within the mixing zone of the granite and dyke at Sambro Head. Edge of the crystal shows strong resorption features, and there are multiple plagioclase crystals within the K-feldspar megacryst. (b) Enlarged in a second micrograph on the right is one such plagioclase crystal.

Figure 26 shows a plagioclase crystal from within the granite matrix next to the contact with the dyke. It shows signs of resorption and disequilibrium. The grain is more rounded, not the characteristic euhedral shape.

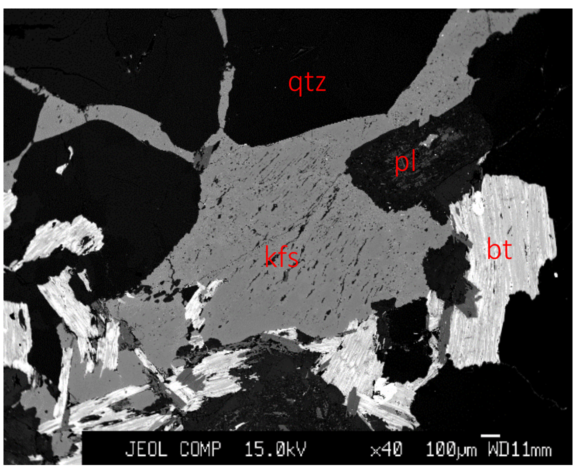


Figure 26. BSE image of Sample 3-3. Shows a partially resorbed K-feldspar crystal within the granite matrix next to the contact with the dyke.

4.6.1.2 Element Maps

Sambro Head

The X-ray maps in Figure 27 display the concentrations of specific major elements across a K-feldspar megacryst in Sambro Head. This megacryst was trapped and subsequently grew within the mixing zone of the dyke and the granite. The top edge of the crystal was mapped and an increase in barium concentration can be observed as you move from the rim of the crystal towards the core to the bottom left. This is illustrated by the change from a darker blue to the green in the barium element. This suggests barium zoning textures may have been present within the K-feldspar megacrysts at Sambro Head, however been overprinted by the resorption textures caused by the intrusion of the dyke.

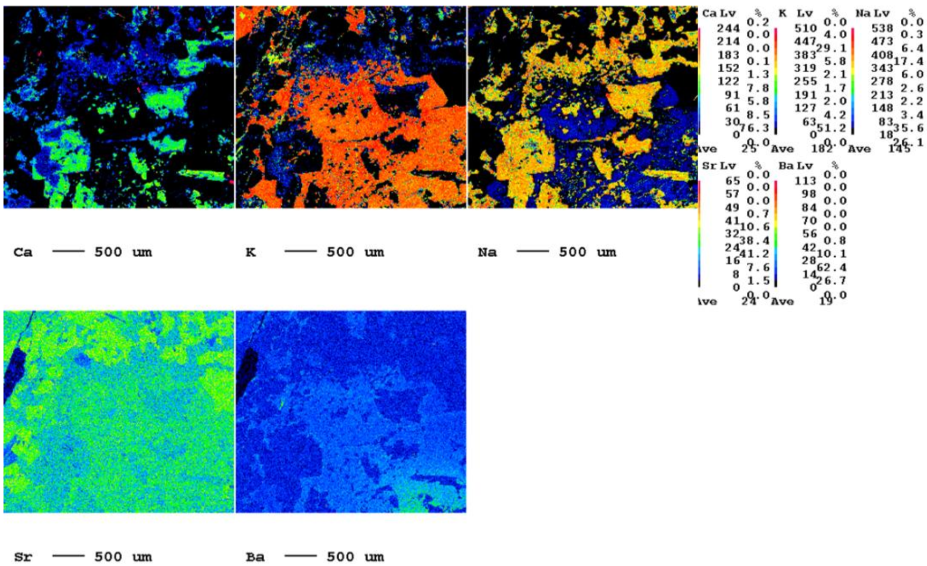


Figure 27. Sample 4-6. X-Ray Map of a K-feldspar crystal from Sambro Head. The colours depict the changing concentrations of the element in the crystal.

Prospect

Figure 28, an element map of a K-feldspar megacryst from Prospect, very clearly illustrating the oscillatory zoning in the crystal. As you traverse from core to rim of this K-feldspar megacryst, the barium goes through large fluctuations in concentration, illustrated in the dark to light blue colours in the map, suggesting multiple zones of resorption. These oscillations are very constant and rhythmic, more so than Peggys Cove. The core of the crystal has the largest concentration of barium and the overall amount decreases towards the rim.

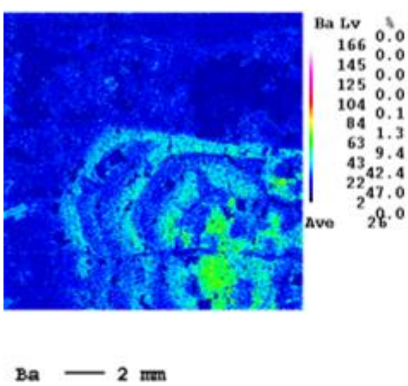


Figure 28. X-Ray map of a K-feldspar crystal from Prospect. The colours depict the changing concentrations of the barium as you move from core to rim.

Peggys Cove

Figure 29 shows an X-ray map across a K-feldspar megacryst in Peggys Cove. It has very strong oscillatory zoning as well as resorption features across the crystal. The barium undergoes large fluctuations in barium concentration as you move from core to rim, illustrated by the changing colours from bright to dark blue. One notable feature in the Peggys Cove K-feldspar is the strong decrease in barium concentration depicted as the very dark blue zone on the crystal, which can be interpreted as a resorption zone. This is proceeded by a large zone of high calcium concentration depicted in light blue and then smaller oscillatory zones following this. The K-feldspar oscillatory zoning at Peggys Cove is much less rhythmic than Prospect and from the observed textures it can be suggested that the K-feldspar megacrysts appear to have undergone more resorption.

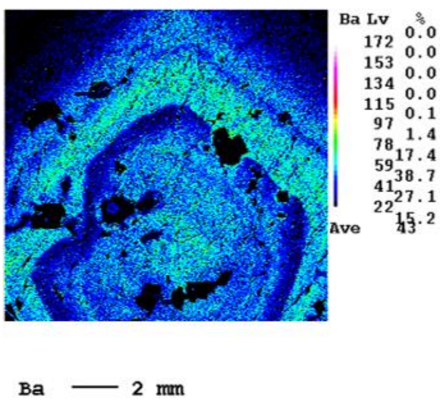


Figure 29. X-Ray Map of a K-feldspar crystal from Peggys Cove. The colours depict the changing concentrations of the barium as you go from core to rim.

4.6.1.3 Line Scans

Using the WD-spectrometer, we collected multiple line scans across a varied number of K-feldspar crystals in order to analyze the change in composition across zones of interest. We then graphed these line scans using excel, plotting the elemental weight percent versus a specified distance.

Sambro Head

Figure 30 graphically displays line scan data taken across a K-feldspar megacryst from Sample 4-6, a xenocryst that was trapped in the mixing zone of the granite and the dyke. 20 points were plotted, using a 5µm step size. The barium weight percent in the megacryst shows a steady decrease in barium content; however, there are four periods of oscillation where the barium content increased. After 250 µm the barium content increases slightly, this could be an effect of the resorbed edge of the crystal as it underwent disequilibrium.

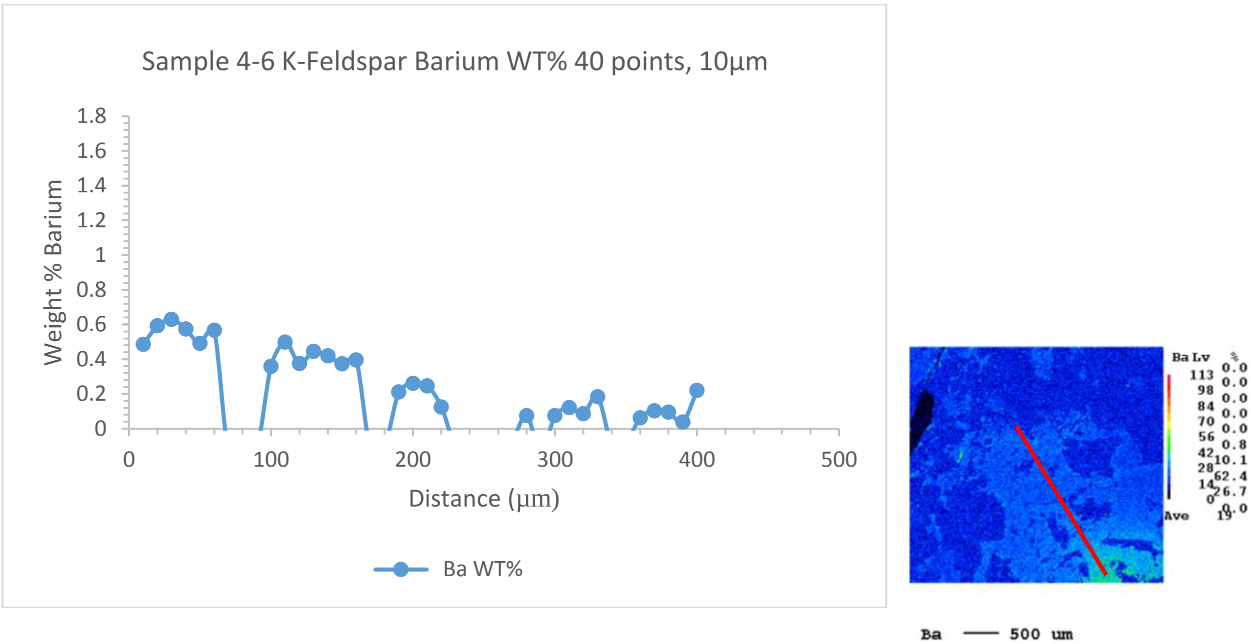


Figure 30. Sample 4-6. Line scan of the weight percent barium versus distance across a K-feldspar crystal located in the mixing zone of the granite and the dyke.

Figure 31 displays line scan data of 20 points taken across the length from core to rim of the K-feldspar megacryst of the panorama in Figure 21. This megacryst partially grew within the mixing zone of the dyke and the granite. This crystal is sampled from the same area as Figure 30 however shows a different barium weight percent concentration pattern. The crystal shows a lower overall barium concentration and the oscillations are smaller less rhythmic than the crystal from Sample 4-6. This could be because these particular xenocrysts from Sample 4-6 was trapped longer inside the dyke and therefore more of the barium had a chance to be resorbed as the xenocrysts grew.

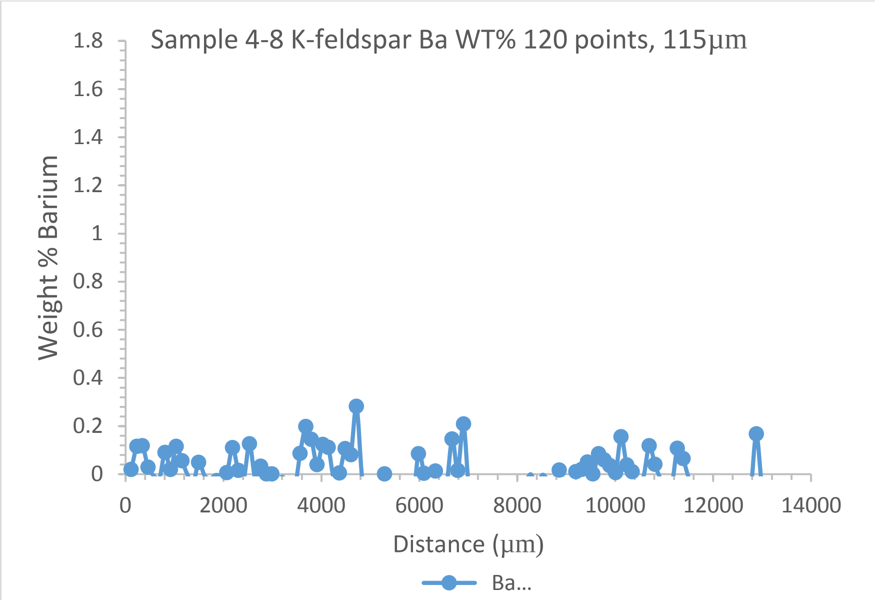


Figure 31. Sample 4-8. Line scan taken across the core to rim of a strongly resorbed K-feldspar megacryst sampled from the mixing zone of the dyke and the granite.

Prospect

Figure 32 shows the barium weight percentage from a line scan across a K-feldspar megacryst from Prospect. 120 points were plotted, with a 60µm step size. Up to four oscillations in the barium weight percent can be observed as you traverse the megacryst from core to rim. The oscillations are very rhythmic. Overall, the total weight percent barium in Prospect is much higher than Sambro Head and approximately similar to Peggys Cove.

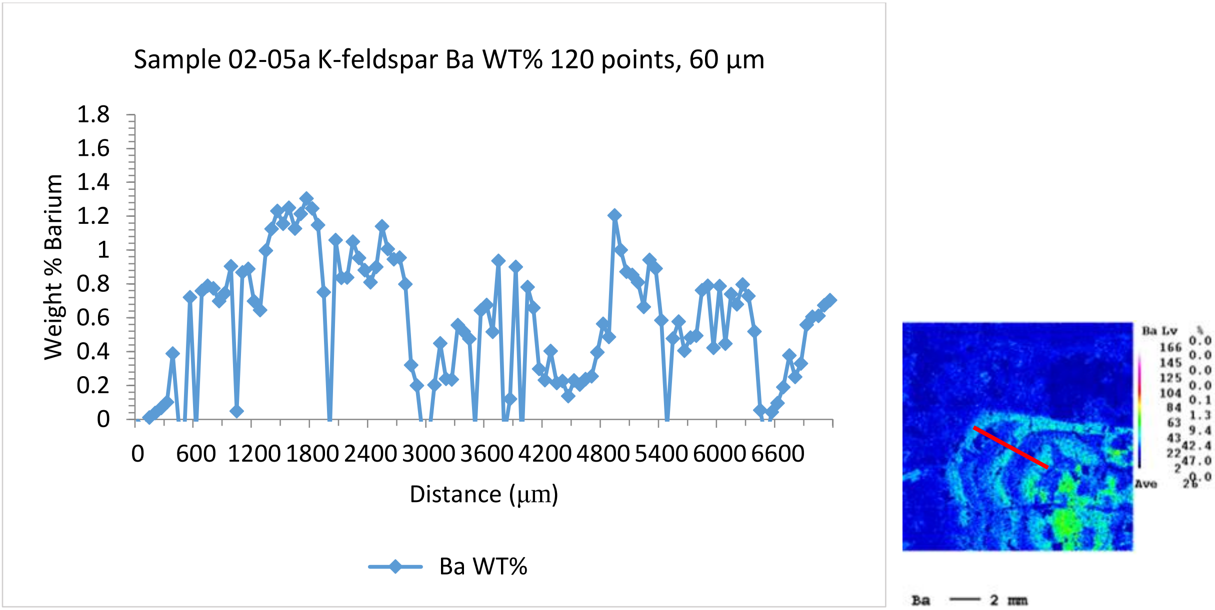


Figure 32. Sample 02-05a. Line scan across a K-feldspar megacryst from Prospect from core to rim. Barium weight % was graphed versus distance (µm).

Peggys Cove

Figure 33 graphically shows a line scan from core to rim of a K-feldspar megacryst sampled from Peggys Cove. 120 points were plotted, using an 115µm step size. The K-feldspar megacrysts at Peggys Cove still show oscillatory zoning, however similarly to the x-ray maps, the zones are not as rhythmic. There is large resorption zone after 2500 µm where there is large drop in barium weight percent. Once the crystal starts to grow again, the zones of oscillation are much smaller. However overall, the total barium weight percent at Peggys Cove is much higher at the start than Prospect and Sambro Head. However, the decrease into zero detectable barium at the rim of the K-feldspar suggests that Peggys Cove was much more resorbed than Prospect.

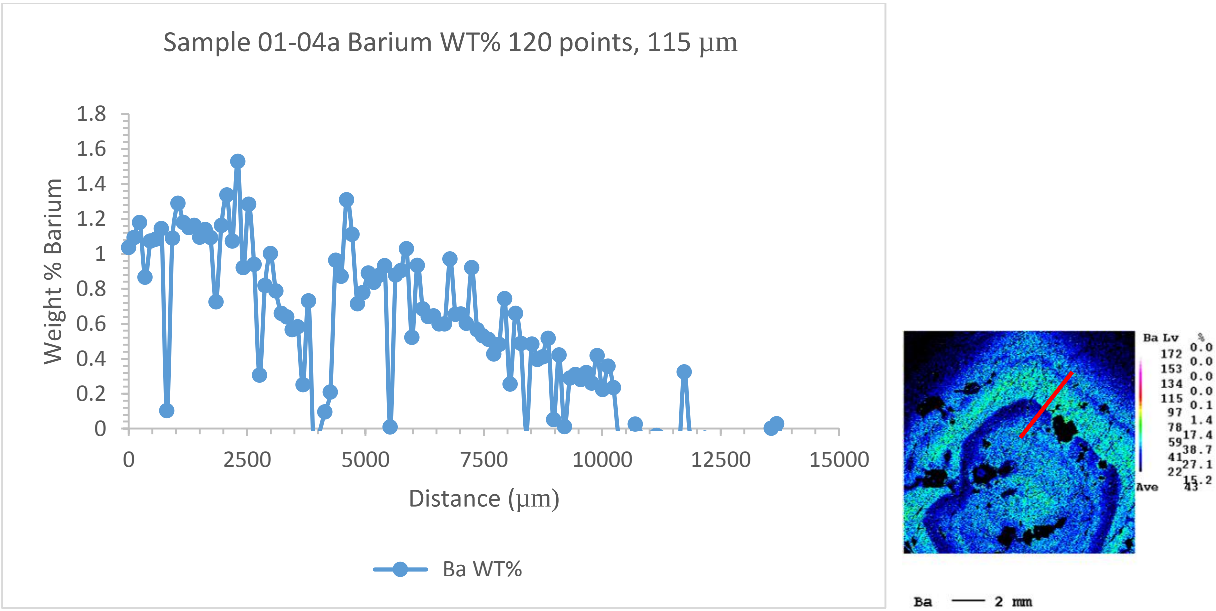


Figure 33. Sample 01-04a. Line scan across a K-feldspar megacryst from Peggys Cove from core to rim. Barium weight % was graphed versus distance (μm).

4.6.2 Plagioclase Textures

4.6.2.1 Micrographs

Sambro Head

Figure 34(a) is a BSE image depicting the tonalitic texture of the dyke matrix. It is composed of mostly quartz, biotite, and highly altered plagioclase. The plagioclase cores have been altered into sericite, a byproduct of hydrothermal alternation of plagioclase. The fluids likely came from when the dyke injected into the hydrous granite. Figure 34(b) shows a plagioclase crystal where some oscillatory zoning textures were preserved. Figure 35 is a BSE image of plagioclase crystals that were sampled from the granite matrix, directly adjacent to the contact with the dyke. These plagioclase crystals show the same alteration textures that can be seen within the plagioclase crystals in the dyke. The hydrothermal fluids caused sericite alteration of the cores in the plagioclase within the granite next to the contact as well as the dyke intruded in.

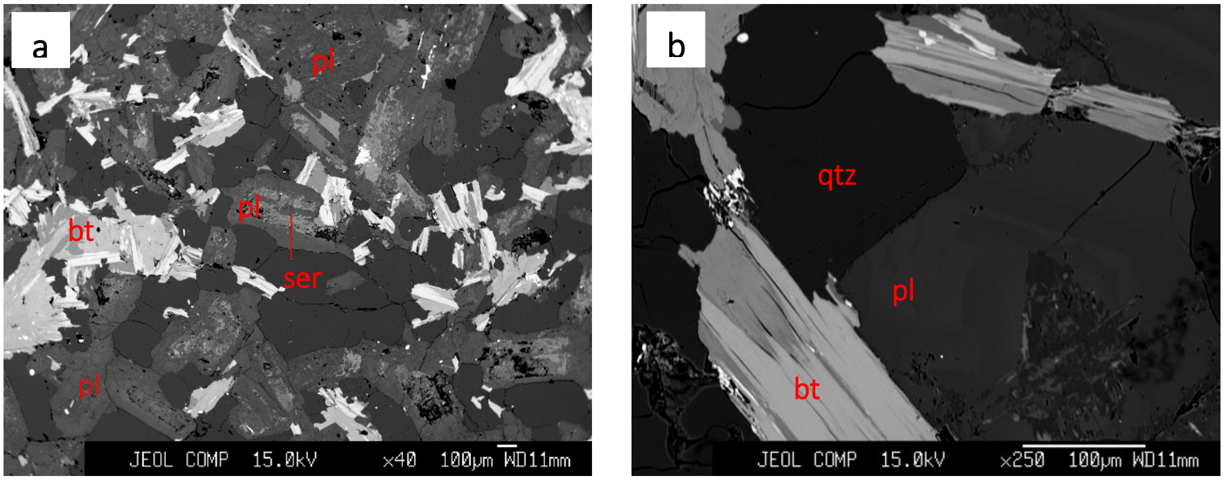


Figure 34. BSE image of Sample 1-7. (a) Showing tonalite matrix of the dyke with multiple highly resorbed zoned plagioclase and clumped biotites as well as a high frequency of quartz. (b) Enlarged image of plagioclase crystal, where some oscillatory zoning can be observed.

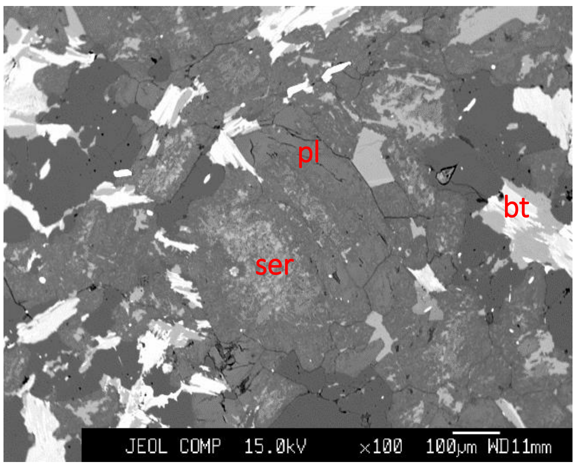


Figure 35. BSE image of Sample 3-3. Multiple highly altered plagioclase crystals within the granite matrix, directly adjacent to the contact with dyke.

Prospect

Figure 36 (a) and (b) depict BSE images of two plagioclase crystals from Prospect. One plagioclase crystal was split into two images, showing the top (a) and bottom (b) of the crystal separately in order to encapsulate the complete crystal into the field of view. Image (c) best illustrates the oscillatory zoning textures (red dashed lines) that are present within the plagioclase crystals. There is also slight indication of this pattern as you traverse from core to rim of the crystal in image (a) and (b); however, these zoning patterns are much less rhythmic in this crystal than in the second plagioclase crystal in image (c).

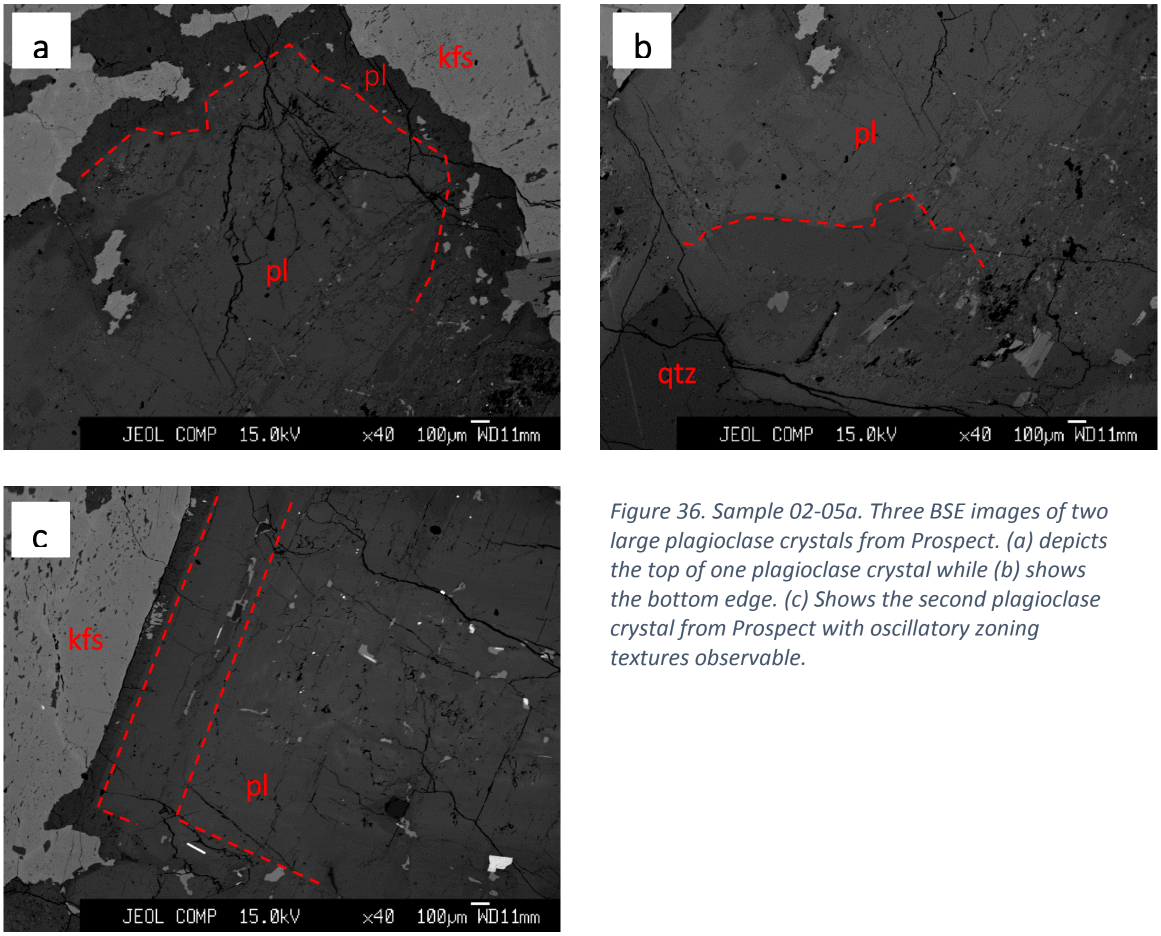


Figure 36. Sample 02-05a. Three BSE images of two large plagioclase crystals from Prospect. (a) depicts the top of one plagioclase crystal while (b) shows the bottom edge. (c) Shows the second plagioclase crystal from Prospect with oscillatory zoning textures observable.

Peggys Cove

We took one BSE image of a K-feldspar plagioclase from Peggys Cove, shown in Figure 37. Zoning is observable within this crystal, outlined in red. The plagioclase crystal is much less euhedral than the megacrysts observed at Prospect, and showing strong resorption textures. The zoning is much less rhythmic than plagioclase observed at Prospect.

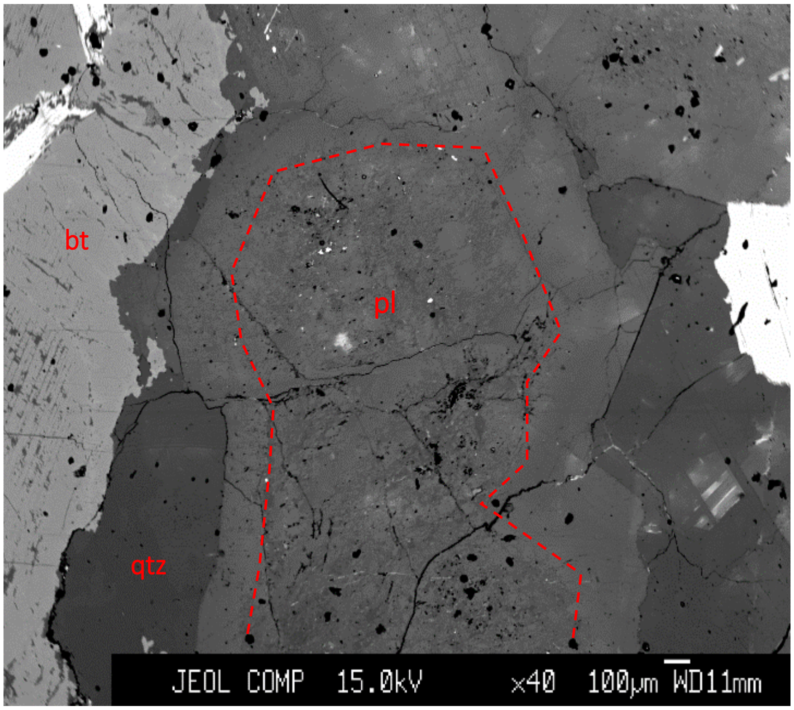


Figure 37. Scanning electron image of a Peggys Cove K-feldspar. The crystal shows patterns is not euhedral, and shows resorption textures.

4.6.2.2 Element Maps

Sambro Head

Figure 38 shows a plagioclase crystal that grew as an inclusion within the K-feldspar megacryst from Figure 25 above. There is not a direct relationship between the calcium and the sodium in this crystal, dissimilar to what is observed in plagioclase that grow outside of the K-feldspar megacrysts. This crystal shows many signs of resorption and the calcium content is not constant throughout the whole crystal.

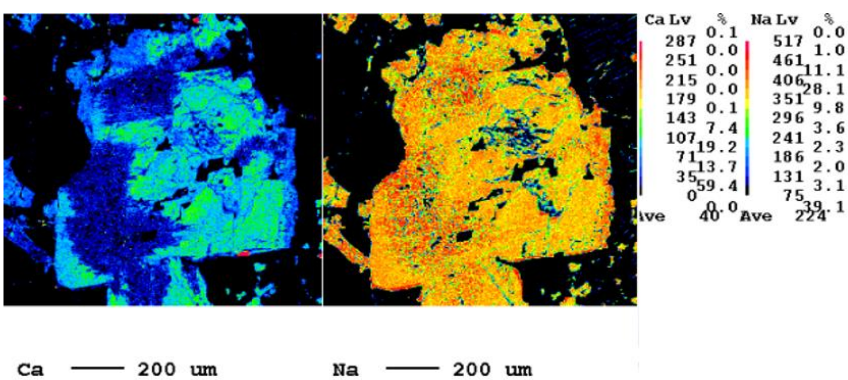


Figure 38. Sample 4-6. X-Ray Map of a plagioclase crystal that grew inside the K-feldspar megacryst above. This plagioclase crystal likely grew as an inclusion after the K-feldspar crystal grew within the dyke at Sambro Head.

Figure 39 shows multiple plagioclase crystals that grew within the tonalitic matrix of the dyke at Sambro Head. Strong zoning can be observed in the calcium and sodium in these crystals. The core of the crystals are much more calcic than the rim, which is highly depleted in calcium and appear to be very sodic.

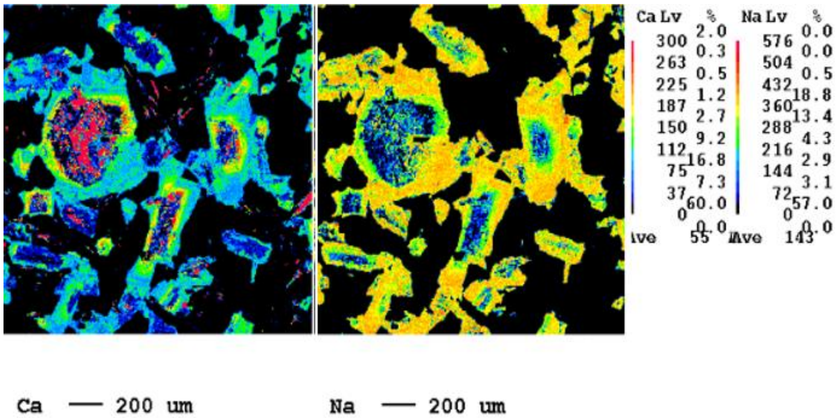


Figure 39. Sample 1-7. X-Ray Map of multiple plagioclase crystals inside the matrix of the dyke, sampled closer to the center of the intrusion

The calcic core and sodic rim pattern observed in the plagioclase crystals holds true in the x-ray maps (Figure 40) of the plagioclase crystals that grew within the granite, next to the dyke contact at Sambro Head. However, the core of these plagioclase crystals have a lower calcium concentration than the ones that grew within the dyke, and in particular have a much thicker rim of sodium around the edges, indicating calcium depletion must have occurred sooner. They are less euhedral than the plagioclase from within the dyke, and show signs of alteration.

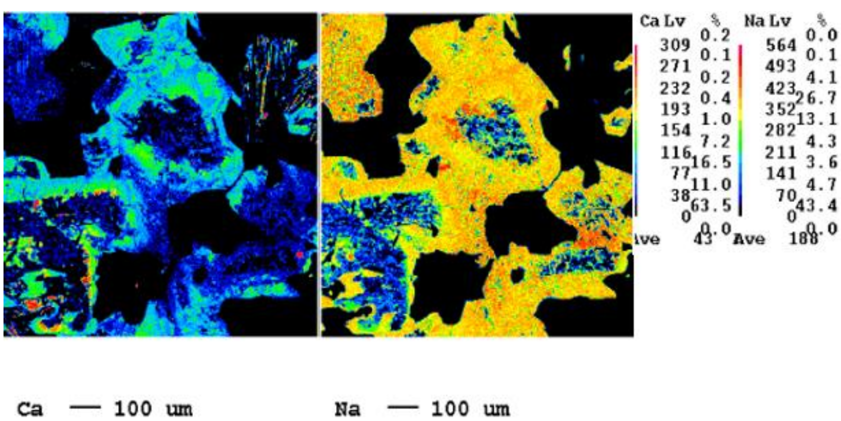


Figure 40. Sample 3-3. X-Ray Map of multiple plagioclase crystals inside the matrix of the granite adjacent to the contact at Sambro Head.

Prospect

Two plagioclase crystals at Prospect were analyzed to create x-ray maps of their major element concentration distribution. Figure 41 shows two distinct zones of varying calcium and sodium concentrations. The first is a very thin zone of higher calcium concentration closer to the core of the plagioclase. The second zone is the abrupt change in calcium and sodium concentrations at the rim of the crystal, suggesting a change in melt composition or resorption. The second plagioclase crystal analyzed at Prospect depicted in Figure 42 shows much more rhythmic zoning than the first plagioclase in Figure 41, suggesting perhaps that this crystal circulated more around the melt. There is an apparent change in composition between the core and rim of this plagioclase crystal, suggesting it underwent resorption and regrowth.

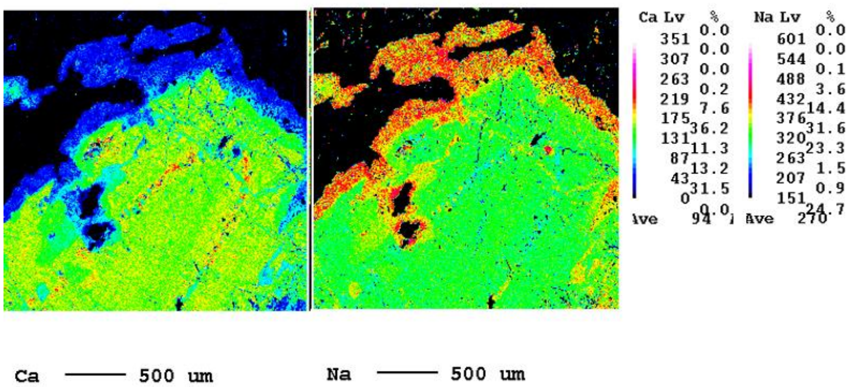


Figure 41. Sample 02.05a. X-Ray Map of a plagioclase crystal from Prospect. The colours depict the changing concentrations of the sodium and calcium in the crystal.

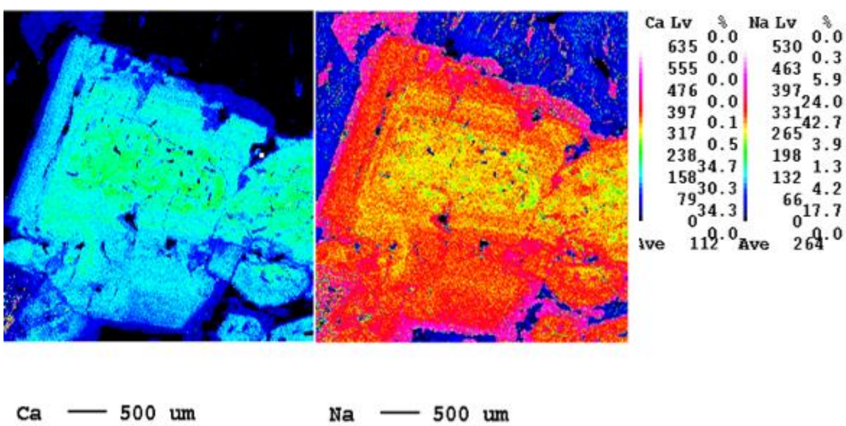


Figure 42. X-Ray Map of a plagioclase crystal from Prospect. The colours depict the changing concentrations of the sodium and calcium in the crystal with multiple oscillatory zones.

Peggys Cove

Figure 43 depicts an x-ray map created from a plagioclase crystal at Peggys Cove. This crystal shows textures that indicate there has been a great deal of resorption occurring at this locality. There is no obvious rhythmic zoning of the sodium and calcium and it appears as if the crystal resorbing and breaking down into subgrains.

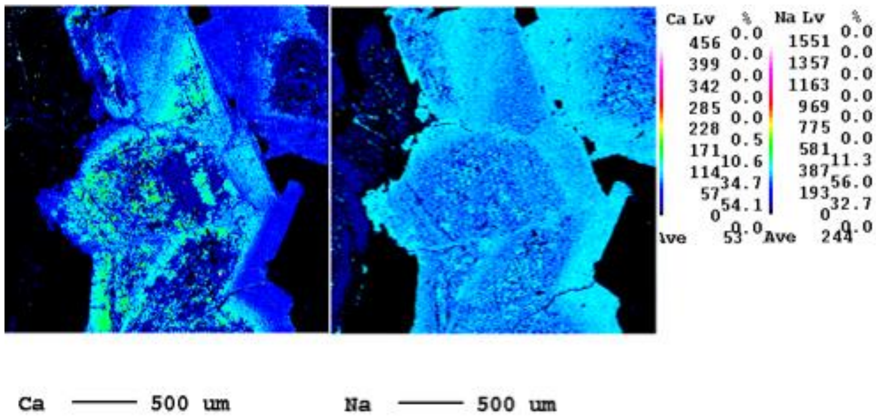


Figure 43. X-Ray Map of a plagioclase crystal from Peggys Cove. The colours depict the changing concentrations of the calcium and sodium in the crystal. Light blue is a higher concentration than darker hues.

4.6.2.3 Line Scans

Using the WD-spectrometer, we collected multiple line scans across a varied number of plagioclase in order to analyze the change in composition across zones of interest. We then graphed these line scans using excel, plotting the elemental weight percent versus a specified distance.

Sambro Head

The data graphed in Figure 44 illustrates a plagioclase sample that grew at the center of the dyke feature at Sambro Head. 20 points were plotted, with a 3.76 µm step size. This plagioclase crystal does not show much variation in calcium and sodium weight percent, with only very small fluctuations across the crystal, likely textures preserved from crystal circulation within the melt. The graph in Figure 45 illustrates a plagioclase sample that grew at the edge of the dyke at Sambro Head. 20 points were plotted and an 8.6 µm step size was used in this case. A highly altered sericite core was likely the cause of the low concentrations of calcium and sodium at the start of this line scan. There is a decrease in the sodium content and matching increasing in the calcium content at 75 µm across the line scan, suggesting resorption occurred at this point. Past 140µm, there is a second zone of low sodium and high calcium concentrations, perhaps indicative a second zone of resorption. The textures illustrated in Figure 44 suggest the plagioclase growing at the center of the dyke did not undergo much resorption, the concentrations of the melt stayed consistent as the crystal grew. However, the concentrations of the plagioclase crystals located at the edge of the dyke suggest these crystals underwent periods of disequilibrium and resorption.

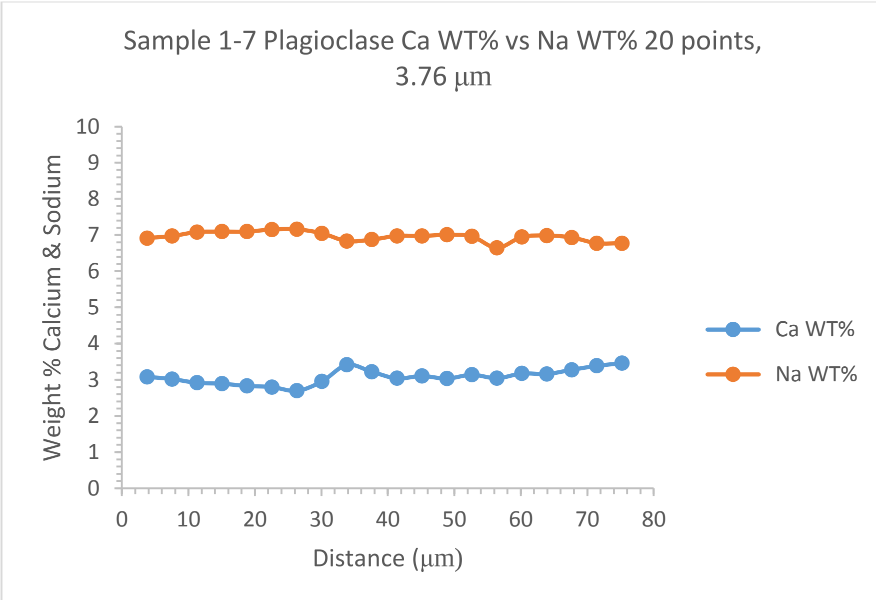


Figure 44. Sample 1-7. Line scan of a plagioclase crystal sample from the center of the dyke at Sambro Head

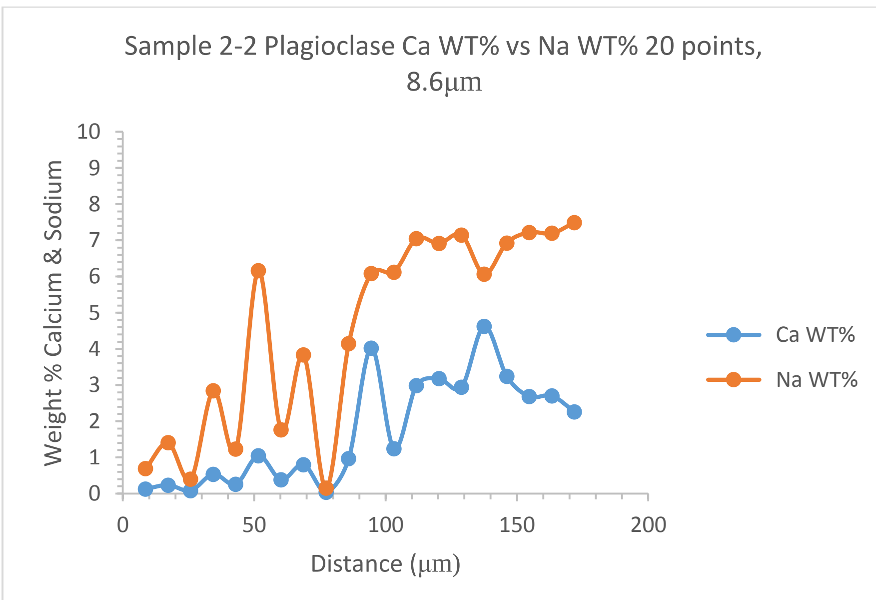


Figure 45. Sample 2-2. Line scan of a plagioclase crystal sample from the edge of the dyke at Sambro.

The strontium weight percent from our K-feldspar megacrysts was not illustrated graphically as there was likely too much interference from the plagioclase. However, we did plot the weight percentage data of the strontium concentrations across a few plagioclase crystals. Figure 46 graphically illustrates the strontium weight percent across a plagioclase crystal sampled from the center of the dyke at Sambro Head. It shows multiple peaks and a large increase in strontium concentration at approximately 75 µm across the line scan. This feature parallels increase in calcium concentrations illustrated inFigure 44 Figure 45. This peak in strontium is possibly a result of a sudden increase in the melt temperature as this crystal was growing, causing resorption of the crystal.

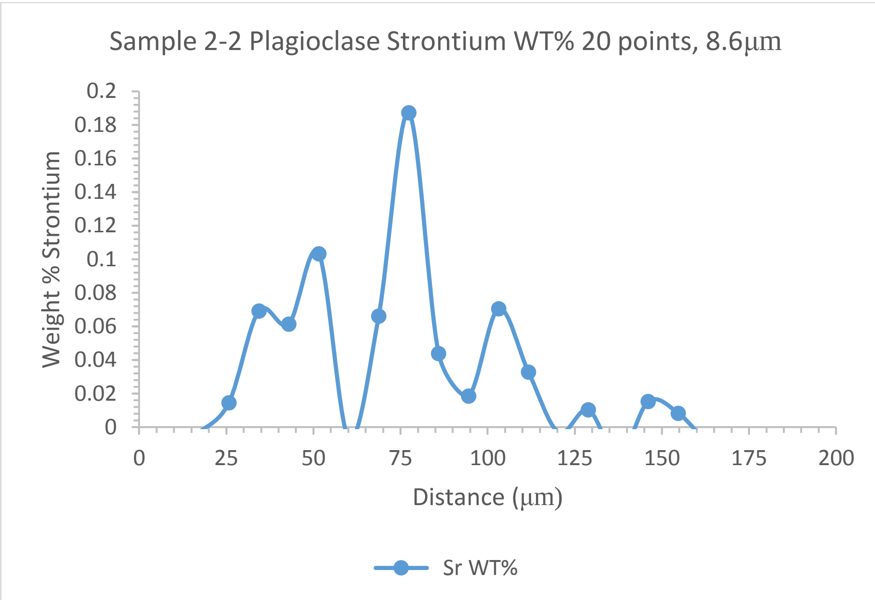


Figure 46. Sample 2-2 Line scan across a plagioclase crystal from the edge of the dyke, illustrating the strontium weight percentage from the core to rim.

Figure 47 shows graphs of a line scan taken of a plagioclase sample that grew within the dyke directly next to the contact of the granite at Sambro Head. 30 points were plotted, with a 24.5µm step size. The calcium and sodium concentrations show a constant pattern across the first section of the line scan, with minor oscillations textures possibly resulting from the crystal circulating within the melt. After 500 µm, there is a sudden change in which the calcium concentration decreases while the sodium concentration increases. This textural pattern could indicate a zone of resorption, or a period of hiatus after which the crystal commences growth again under different melt concentrations. The intrusion of the dyke could be suggested as a cause of the alteration in melt composition at this point in the line scan.

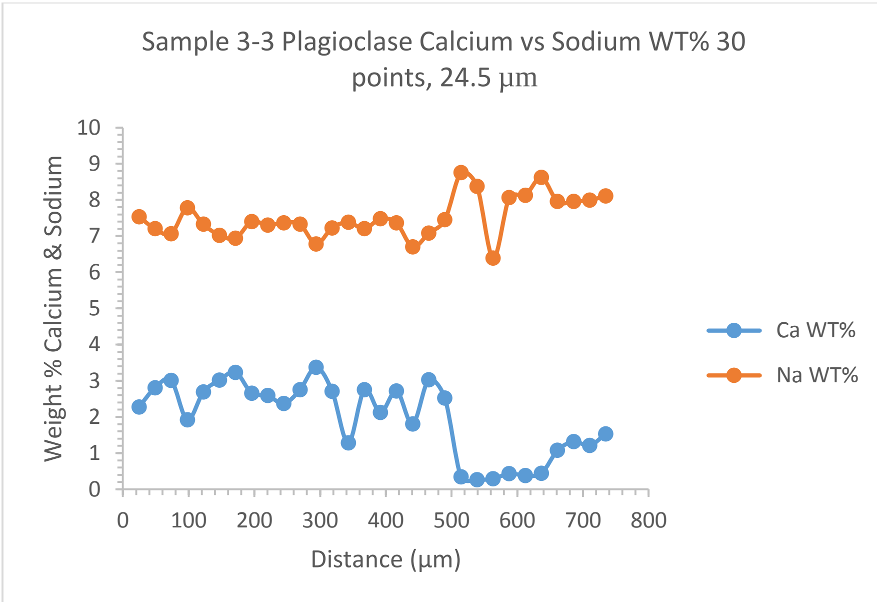


Figure 47. Sample 3-3. Line scans taken from a plagioclase sample that grew within the dyke next to the contact of the granite.

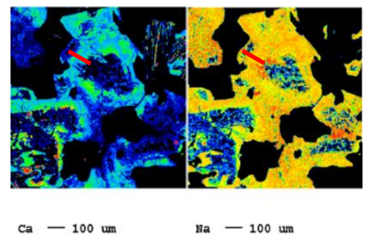


Figure 48 illustrates the strontium weight percent within the plagioclase crystal in Sample 3-3. The concentration of strontium within the granite is much lower than the strontium from the plagioclase in the dyke in Figure 46. It shows minor fluctuations as the crystal was growing with multiple zones where the barium concentration drops below the detection limit. This pattern corresponds with the sudden decrease in calcium concentration in Figure 47 above, a texture likely a result of resorption of the plagioclase crystal in the melt.

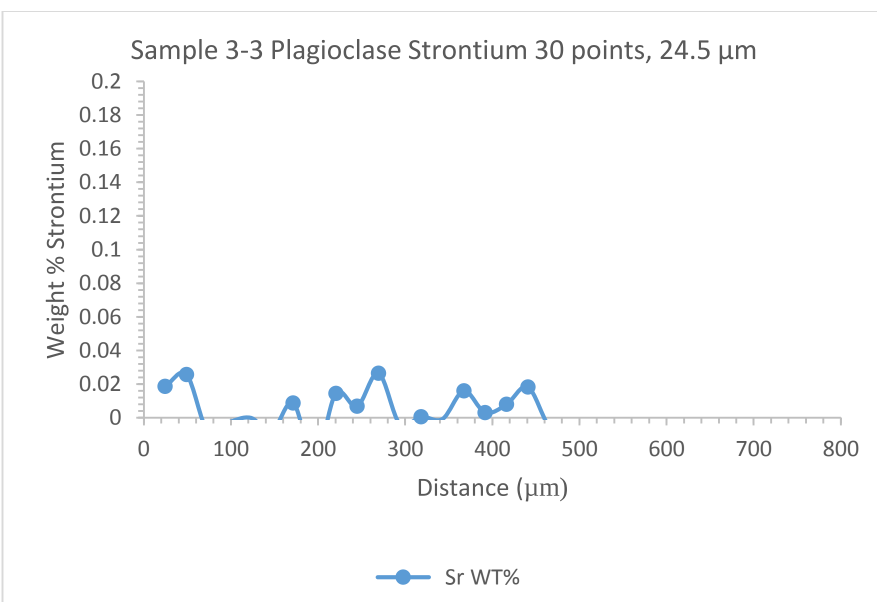


Figure 48. Sample 3-3. Line scans taken from a plagioclase sample that grew within the dyke next to the contact of the granite.

Figure 49 graphically displays line scan data taken across a plagioclase from sample 4-6, within the mixing zone of the granite and the dyke. 20 points were plotted, with a 5µm step size.

The calcium and sodium are a constant weight percentage until 40µm across the line scan, after which they decrease and increase respectively, indicating this crystal was not in equilibrium with the melt at this point in its growth history.

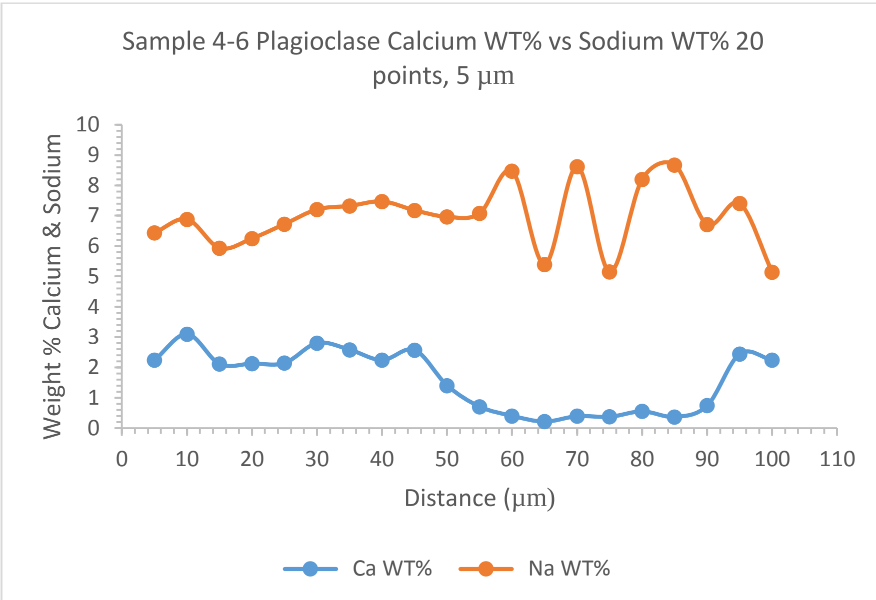
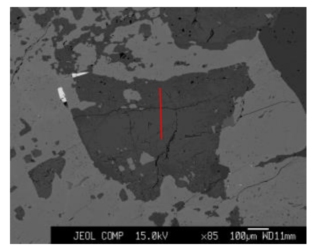


Figure 49. Sample 4-6. Line scan of the weight percent calcium and sodium across a plagioclase crystal from the mixing zone of the granite and dyke



The strontium weight percentage in the plagioclase crystal shows very low amounts of strontium with small oscillations throughout. The overall strontium weight percent in the Sambro Head samples is much lower than the strontium concentrations in the Prospect and Peggys Cove plagioclase samples. The largest increase in strontium concentrations occur from 35-90 µm, which likely indicates a resorption texture from an increase in melt temperature. This concentration pattern occurs at a similar interval in the calcium and sodium concentrations illustrated in Figure 49.

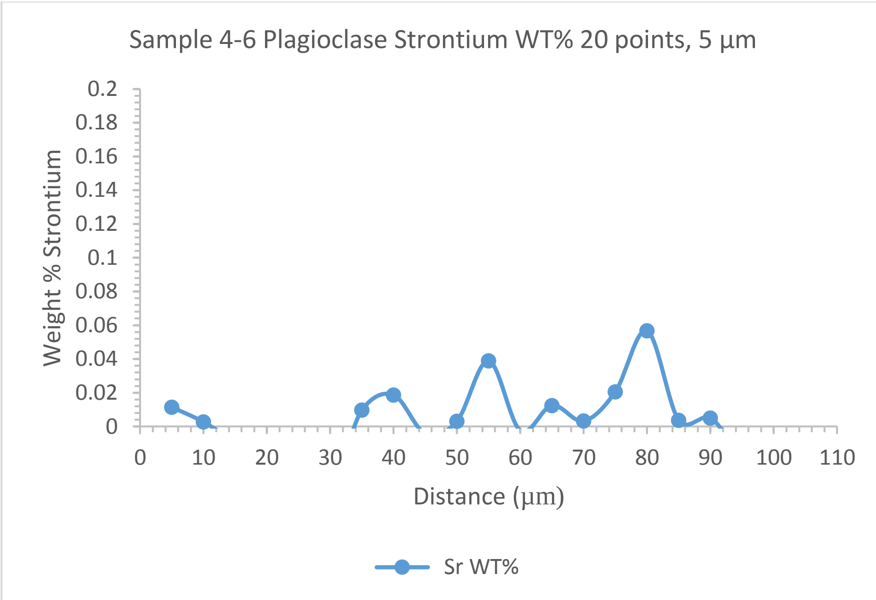
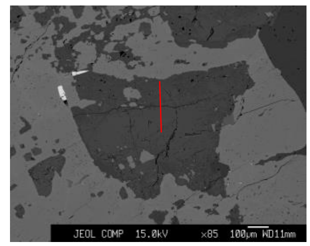
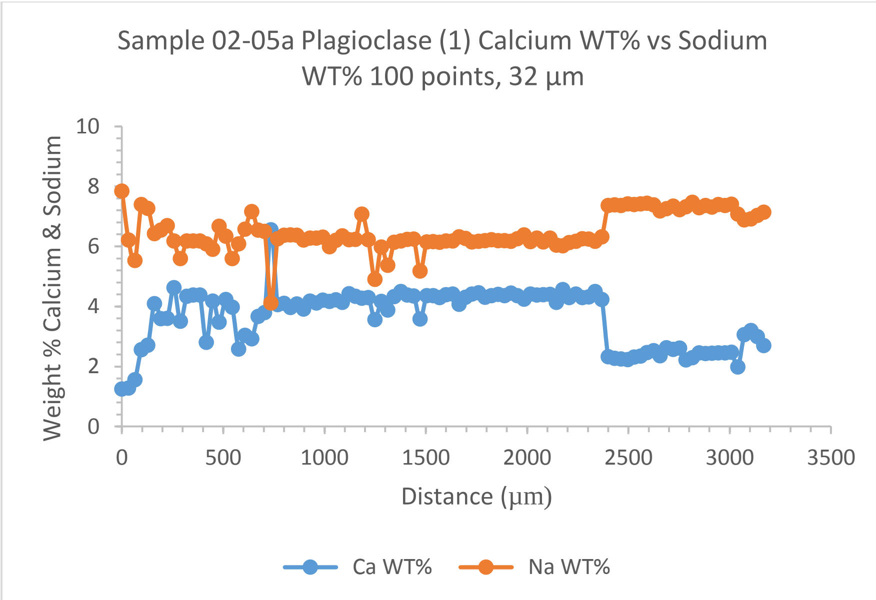


Figure 50. Sample 4-6. Line scan of the weight percent strontium across a plagioclase crystal from the mixing zone of the granite and dyke



Prospect

Figure 51 shows the weight percentage of sodium and calcium from the core of the plagioclase crystal to the rim. This crystal was sampled from the granite at Prospect. 100 points were plotted with 32µm step size. The sodium and calcium concentrations are constant between 500 and 2500 µm, with only minor oscillations that are likely recording the crystal circulating within the melt. Ensuing this pattern, there is a sudden decrease in the calcium concentration with an equivalent increase in the sodium concentration. This texture suggests a hiatus in crystal growth after which the crystal continued growing in a more sodic melt composition. Figure 52 illustrates the calcium and sodium concentrations across a second plagioclase crystal from Prospect. The calcium and sodium show strong oscillation patterns as you traverse to the rim, likely also a result of the crystal circulating through the melt. The sudden drop in concentrations at 2400 µm indicate resorption of the crystal occurred. Following this, the concentrations indicate that the crystal grew steadily in equilibrium.



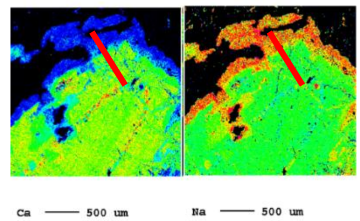
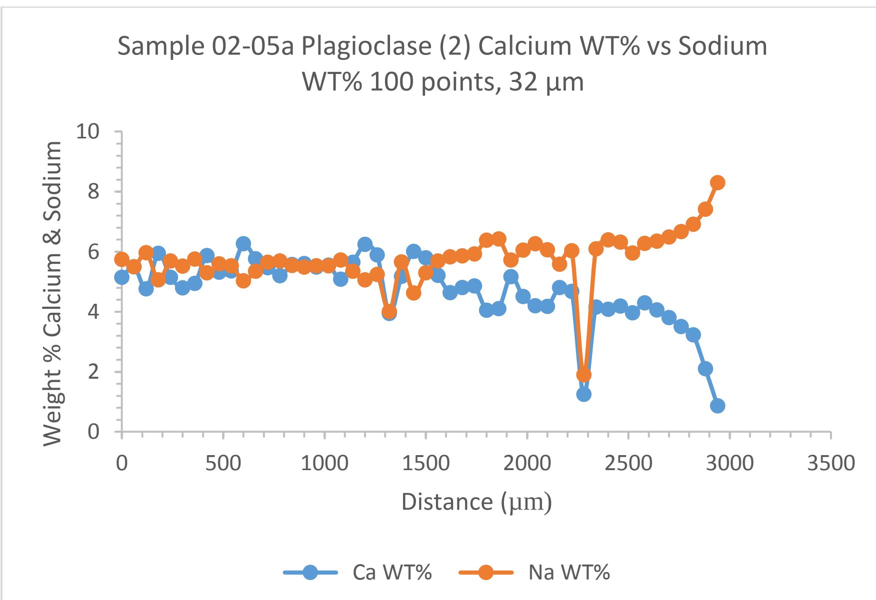


Figure 51. Sample 02-05a, plagioclase (1). Line scan of a crystal from Prospect



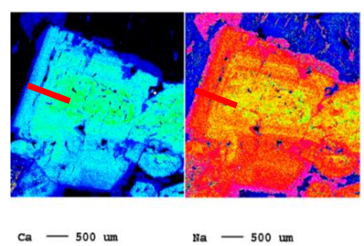


Figure 52. Sample 02-05a, plagioclase (2). Line scan of a plagioclase crystal from Prospect

Figure 53 illustrates the weight percent strontium across the plagioclase crystal from the granite at Prospect. It shows regular oscillations that strongly agree with the calcium oscillations in Figure 51 above. Large zones of resorption occurred frequently as evidenced by the large increases in strontium concentrations. After 2500 µm, the strontium decreases to very small concentrations and at some points is below the detection limit. Figure 54 illustrates the weight percent strontium across a second plagioclase crystal. The strontium strongly parallels the calcium from Figure 51 decreasing steady until 2500 µm, where it spikes up again, likely a result of crystal regrowth commencing after a period of hiatus.

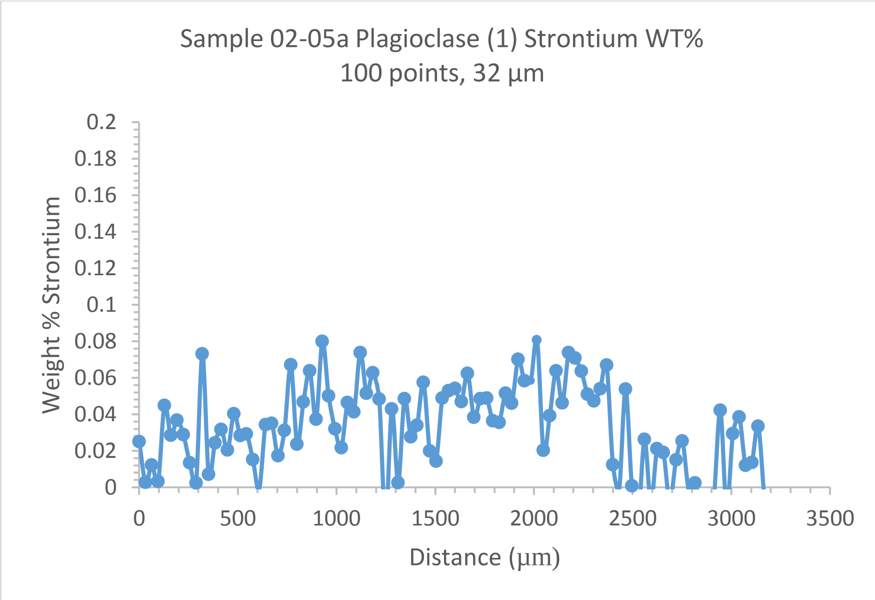


Figure 53. Sample 02-05a, plagioclase (1). Line scan of the weight percent strontium across a plagioclase crystal from Prospect.

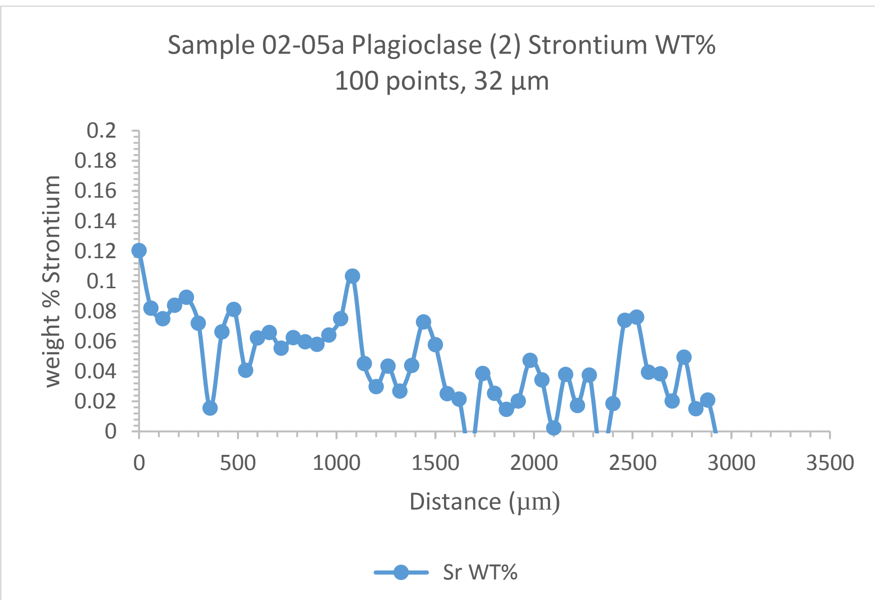
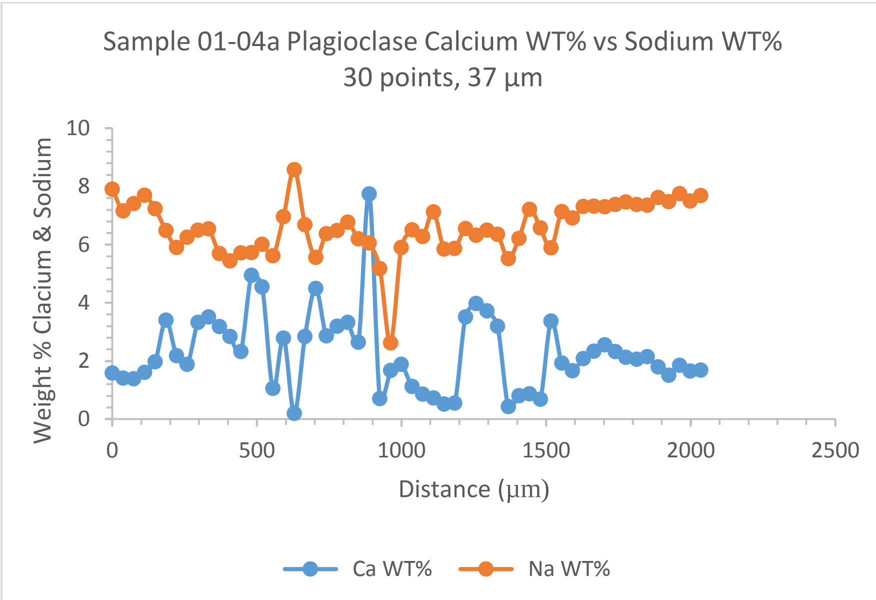


Figure 54. Sample 02-05a, plagioclase (2). Line scan of the weight percent strontium across a plagioclase crystal from Prospect.

Peggys Cove

Figure 55 shows the weight percentage of sodium and calcium across a selected plagioclase zone. 30 points were plotted using a 37µm step size. The sodium and calcium display an inverse relationship, sodium decreases at first while the calcium increases. This pattern continues until approximately 740 µm, in which the opposite occurs. The patterns of oscillation are less rhythmic than the concentrations observed at Prospect and furthermore, the textures indicate a large zone of resorption within this plagioclase crystal at Peggys Cove, a greater amount than what the textures at Prospect or Sambro Head display.



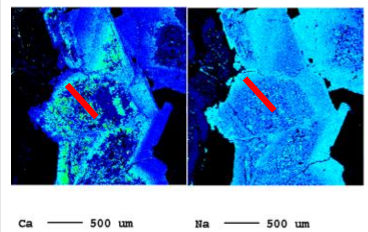


Figure 55. Sample 01-04a. Line scan of the weight percent strontium across a plagioclase crystal from Peggys Cove

Figure 56 depicts a line scan across a plagioclase megacryst from Peggys Cove. The strontium weight percentage was illustrated graphically. 30 points were plotted, with a 37µm step size. The graph displays a bell-shaped pattern. The weight percent strontium is low at the start, and then is proceeded by a global maximum of 0.14 weight percent strontium at approximately 750 µm, halfway from the core to the rim. The amount of strontium then progressively decreases as you move towards the rim of the plagioclase crystal. The large oscillations in the strontium concentrations match the calcium concentration oscillations shown in Figure 55.

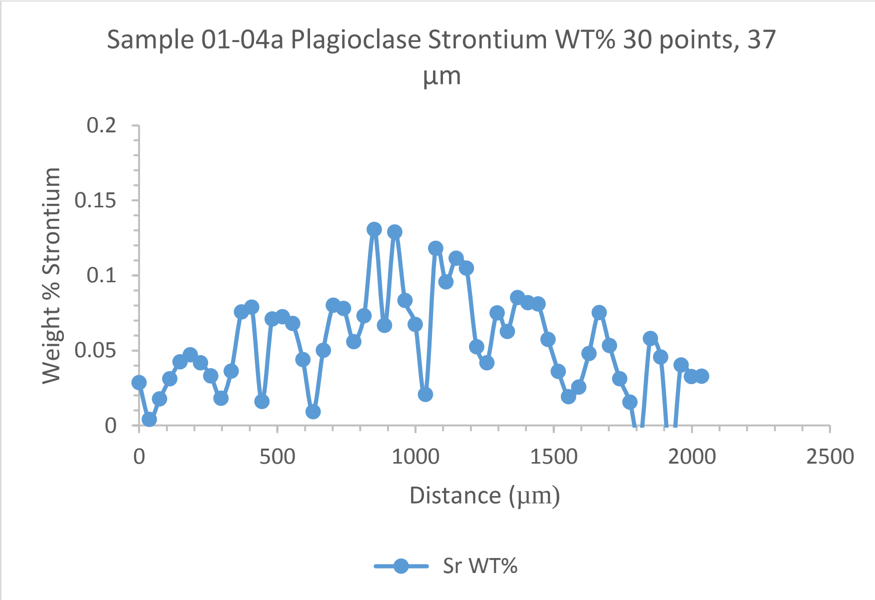
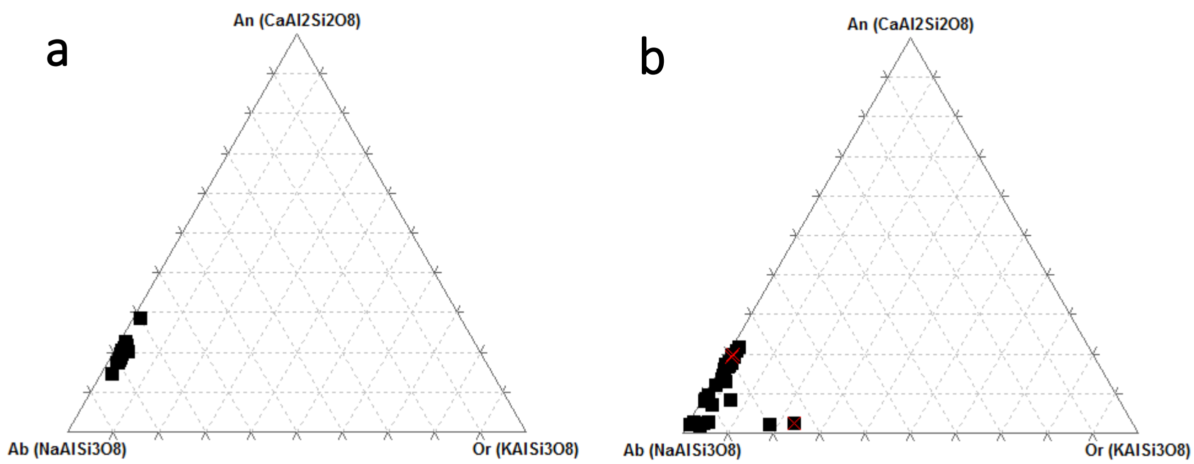


Figure 56. Sample 01-04a. Line scan of the weight percent strontium across a plagioclase crystal from Peggys Cove

4.6.2.4 Triplots

Sambro Head

We used the WD-spectrometer to collect individual point data from multiple plagioclase crystals at different localities across the Sambro Head samples. These were plotted on to a tertiary diagram in Figure 57(a), (b) & (c). Figure 57(a) shows a plagioclase crystal from the centre of the dyke. The plagioclase within the centre of the dyke is much more calcite in comparison with the plagioclase from the edges of the dyke and within the mixing zone. Figure 57(b) shows a plagioclase crystal from the edge of the contact with the granite, and the red X's mark points taken from plagioclase next to the contact within the granite matrix, to explore if there was any chance in composition across the contact. It shows that both the plagioclase within the granite matrix and the dyke have a strong sodic composition. Figure 57(c) shows a plagioclase crystal from the mixing zone of the dyke and the granite, where plagioclase crystals grew within the granite originally then were subsequently trapped within the dyke. The concentrations are very sodic rich; however, there are many anomalous points with a ternary composition as well that trend along the bottom axis. These ternary points indicate that those crystals must have grown at a higher average temperature, in order to develop higher potassium concentrations.



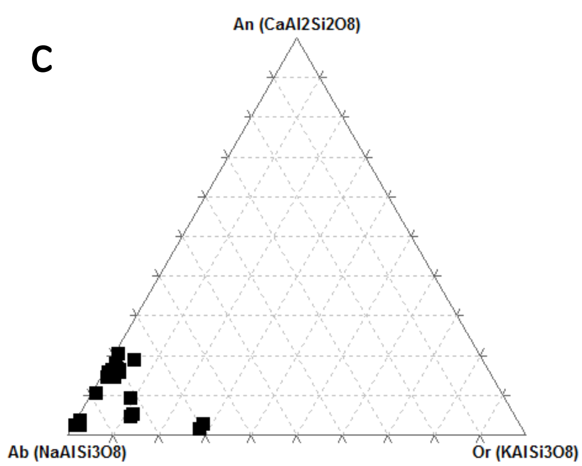


Figure 57. Tertiary Diagrams of Sambro Head Plagioclase. (a) Sample from centre of dyke (b) Samples from within the dyke matrix and within the granite matrix (X symbol) (c) Sample trapped within mixing zone of dyke and granite

Prospect

Once again, we used the WD-spectrometer to collect individual point data from multiple plagioclase crystals at different localities in Prospect. These were plotted onto a tertiary diagram in Figure 58(a) & (b). Figure 58(a) illustrates 30 points collected closer to the core of the crystal and Figure 58(b) displays 30 points nearer to the rim of the crystal. The tertiary diagrams depict similar patterns to the line scan data and the element maps: the rim of the crystal is much more sodic than the core of the crystal, which is more calcite rich. Overall, the plagioclase at Prospect shows very low levels of potassium, plotting almost directly along the An-Ab side of the diagram.

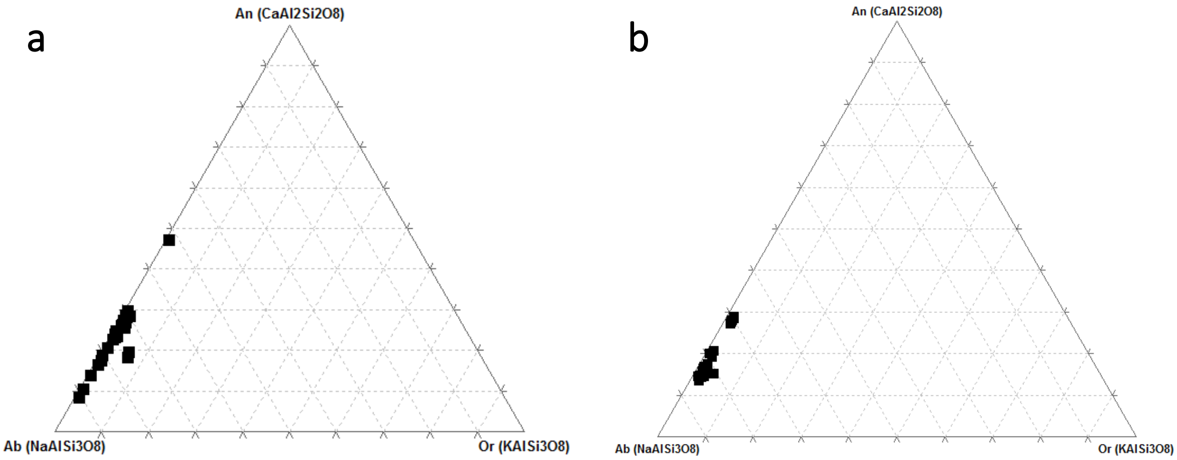


Figure 58. Tertiary Diagrams of a Prospect plagioclase. (a) Points closer to core of crystal (b) Points closer to the rim of the crystal.

Peggys Cove

Figure 59(a) & (b) are triplots illustrating the plagioclase composition from Peggys Cove. Figure 59(a) illustrates 20 points closer to the core of the crystal and Figure 59(b) illustrates 20 points that were located closer to the rim of the crystal. These triplots replicate the findings in the element maps above; the core of the crystal shows a more calcite rich composition while the rim is much more sodic. The scatter of the plots at Peggys Cove are similar to Sambro Head and Prospect, indicating they grew at similar magmatic conditions. Peggys Cove shows a larger composition distribution and ternary compositions as well indicating these crystals grew at higher average temperatures.

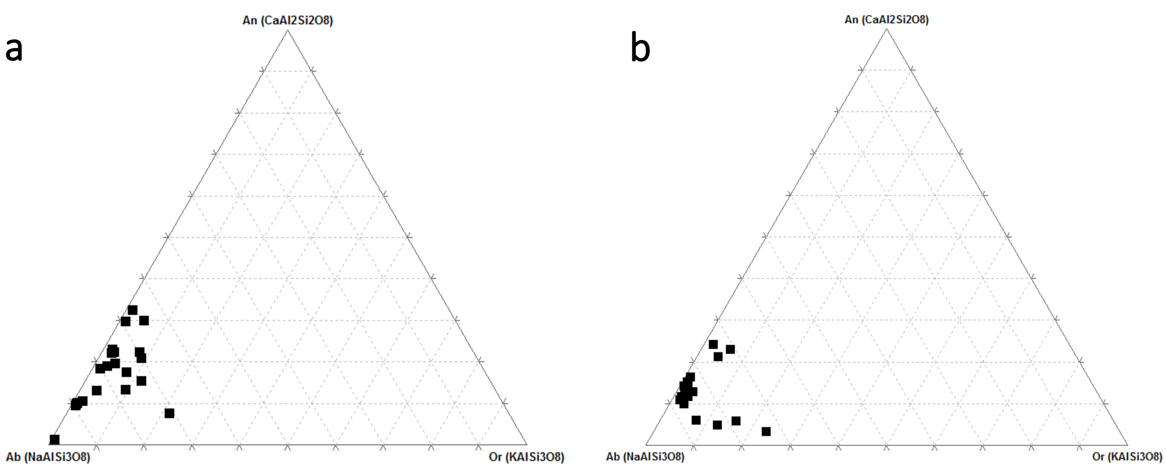


Figure 59. Tertiary Diagrams of a Peggys Cove plagioclase. (a) Points closer to core of crystal (b) Points closer to the rim of the crystal.

Chapter 5: Discussion

5.1 Introduction

Feldspars are extremely susceptible to mafic-felsic magma mixing and mingling, and their recorded textures are an important aid in developing our understanding of pluton emplacement and history. Magma mixing implies some sort of physical and/or chemical interaction between melts of different compositions, which leads to disequilibrium conditions in which these crystals grow. This disequilibrium influences many different textures in the crystals, in particular their nucleation and growth rate as well as composition.

Oscillatory zoning, a common texture that can be associated with hybridization, is caused by circulation of the crystal in the melt. Oscillatory zoning in addition to evidence of resorption and significant variations in temperature sensitive elements or mineral compositions suggests magma mixing and hybridization. There is evidence for these textures at our three localities sampled.

5.2 Field Observations

The main feature of interest at Sambro Head is the presence of a mafic dyke that has intruded and intermingled with the granite. The borders of the dyke are not completely cross cutting the granite; there are sections where the two have clearly mixed (as shown in Figure 12). Xenocrysts, originally from the granite, are found within the dyke, and mafic fragments were torn off the dyke and trapped within the adjacent granite melt. The mingling borders and the presence of xenoliths of both the mafic dyke and the granite indicate that the granite nor the mafic dyke were completely solid upon intrusion. The mingling borders of the dyke and granite indicate that partial hybridization, at least in this particular zone, occurred at this locality. However, there are fewer K-feldspar megacrysts at the center of the dyke in contrast to the edges, indicating that although mixing/mingling occurred at this locality, it was not thorough enough to entrap K-feldspar crystals very far into the melt.

The presence of mafic enclaves (Figure 14) at Prospect, with similar compositions to the dyke at Sambro Head, strongly suggest evidence towards a mafic intrusion that has mixed and mingled with the granite thoroughly enough that the dyke was fragmented and broken up. At the borders of these mafic fragments, we can observe K-feldspar megacrysts cross cutting the boundary, and within these fragments there is a large quantity of K-feldspar xenocrysts. This evidence strongly suggests that not only was the dyke a partial liquid upon intrusion, there was a high degree of mixing/mingling occurring with the granite to allow for the granitic xenocrysts to circulate throughout the resulting mafic fragments.

There was no direct evidence of mafic intrusions at Peggys Cove. However, the presence of mafic dykes is not evidence of mixing; on the contrary it is the absence of mafic dykes at these sites that indicates hybridization. Therefore, the lack of dykes alone could suggest the Peggys Cove section of the Halifax Pluton underwent much more thorough mixing than Prospect or Sambro Head.

The fact that we see evidence of variable mixing at all stages (i.e. whole dykes versus mafic fragments) gives strong probability that the evidence for hybridization will be variable between the areas. The following sections outline the specific textures of the feldspar crystals and evidence for hybridization at these sites.

5.3 K-feldspar Textures

As outlined by Long and Luth (1986), increases in barium concentrations are a common hybridization texture in K-feldspar megacrysts and indicate magmatic intrusions and an increase in the temperature. Barium, an incompatible element, will want to return to the melt once resorption of the crystal occurs, causing a decrease in the overall barium concentration of the crystal edge. As the crystal reaches equilibrium again and begins to regrow the initial growth phase is enriched in barium from the local melt/crystal interface. Multiple injections of higher temperature magma may result in several resorption textures with accompanying increases in barium. Finer scale oscillatory patterns and smaller fluctuations in barium more likely record crystal circulation within the melt.

There is evidence for this oscillatory zoning in all three sites that we sampled in the Halifax pluton. These oscillations suggest an overall slow cooling process with rhythmic pulses of interrupted cooling, producing resorption of the crystals at all three localities. Therefore, similar processes of hybridization occurred throughout this phase of the Halifax Pluton.

The megacrysts at the Prospect and Peggys Cove sections show features suggesting the same magmatic processes, namely circulation within the granitic magma and resorption/regrowth following injection of higher temperature (mafic) magmas. The megacrysts at Peggys Cove have the highest range of barium concentrations, in comparison to Prospect and Sambro Head. The crystals also have slightly less rhythmic barium oscillations than Prospect and show mores signs of resorption. This may suggest that the Peggys Cove section of the granite has undergone a more thorough mixing with a mafic magma, reaching higher average temperature during megacryst growth than the section of granites at Prospect or Sambro Head.

The megacrysts at Sambro Head were only sampled from areas within the granitic host rock and the mafic dyke, which display evidence of mixing/mingling. The megacrysts show evidence of oscillatory barium zoning although with lower overall barium concentrations (0-0.6 WT% barium, Figure 30). Textural evidence recorded by these crystals also overwhelmingly suggests that they have experienced significant resorption and reaction within this general zone of magma mixing. For example, the outer section (up to several millimeters) of these crystals show anhedral and strongly embayed margins, which are entirely depleted in barium (Figure 30). This strongly suggests that they did not regrow after emplacement of the mafic dyke. In addition, megacrysts that have become entrapped in the edge of the mafic dyke and completely separated from the granitic groundmass show the most significant textural and chemical evidence for resorption and reaction. Furthermore, these crystals display highly disrupted barium zoning and mantling by plagioclase (e.g. Rapakivi texture). This texture is commonly associated with hybridization in granitic magmas (Bussy, 1990).

Changes in the barium contents of the granitic magma, to produce increases of barium in the megacrysts, which are between 0.5-1.4 WT% (Figure 32, Figure 33), are unlikely to be caused only by the introduction of barium-rich crustal rocks, or from mafic magmas injected at the time of crystal growth. There are no known country rocks with such high levels of barium and typically, mafic magmas have less barium contents than felsic equivalents.

To sum, the variable extent of magma mixing and hybridization is reflected in the differences recorded by the megacrysts from these three localities. The barium content in the megacrysts at Sambro Head are lower suggesting less complete mixing. At Prospect and Peggys

Cove the barium contents and zoning suggest more thorough mixing, with more complete mixing apparently having occurred at Peggys Cove.

5.4 Plagioclase Textures

The plagioclase textures have similarly recorded variable extents of magma mixing and hybridization. We observed continuous zones from a calcic core to a sodic rim in most all out plagioclase crystals. Many plagioclase grains also exhibited oscillations that superimposed a broader Rayleigh fractionation pattern. This anorthite to albite oscillation pattern in the plagioclase can also be illustrated with a genetic phase diagram for plagioclase in Figure 60. Since the equilibrium conditions of plagioclase trends towards 100% albite, they are growing along the temperature invariant section of the liquidus (shown in red). A small increase in temperature will invoke a substantial increase in the anorthite content before the crystal will regrow. As these crystals are calcium poor and the magma is not calcium rich, the plagioclase crystals will be resorbed and/or experience a hiatus in growth (i.e. Figure 51) until sufficient cooling has occurred and equilibrium growth at the solidus is re-established.

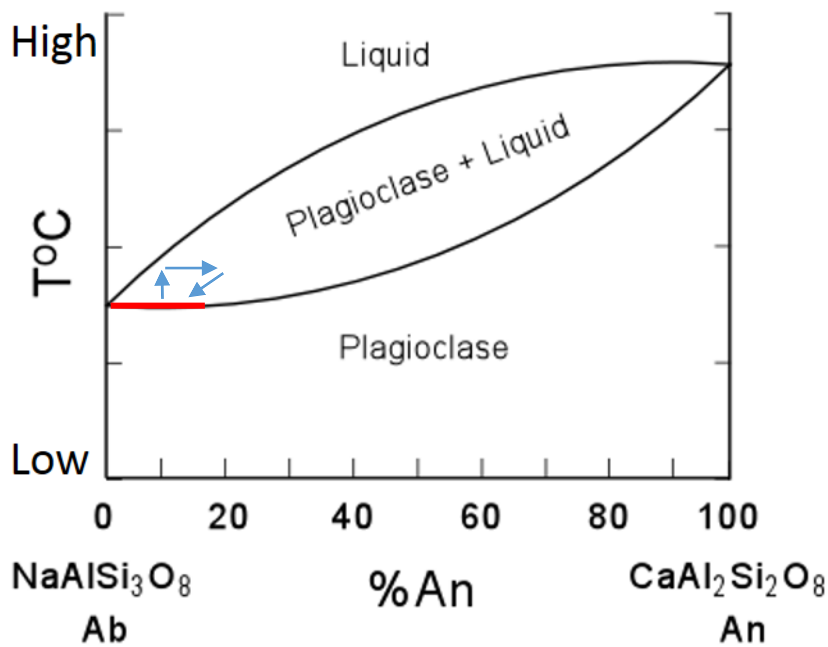


Figure 60. Phase diagram illustrating how a minimal increase in temperature will cause the plagioclase to resorb. The crystal remains in the melt phase up until sufficient cooling has occurred and equilibrium growth at the solidus is re-established.

Prospect plagioclase show a very similar range in composition to Peggys Cove however the plagioclase crystals from Peggys cove appear to be a more ternary composition (Figure 59). This suggests growth at a higher temperature. This is consistent with the observed higher range of barium contents in the K-feldspar megacrysts. The results of two-feldspar thermometry provide further evidence that the average magmatic temperatures at Peggys Cove were higher than the average temperature at Prospect (Wongus, 2013).

The plagioclase in the dykes at Sambro appear from the X-ray maps to be relatively calcium rich however the textures also suggest that these crystals have undergone severe reaction and alteration with hydrous fluids. (Figure 35 and Figure 39). This is a result of the de-watering of the granite as the dyke intruded.

The preserved compositions of the Sambro Head plagioclases from the dyke have slightly higher anorthite contents. However, more obviously, these crystals contain higher potassium contents, i.e. they have a more ternary composition (Figure 57). This can only be explained at growth at a higher temperature, which would be expected for plagioclase crystals in a mafic dyke.

5.5 Multiple Phases of Injection

As the granite was emplaced, it is highly likely and probable that multiple injection events of mafic dykes of some sort were introduced into the granite over the pluton's entire crystallization history. However, it is not likely that evidence of these mafic dykes will not be evidenced everywhere in the pluton. The Weekend Dykes (Ruffman et al. 1990), which cross cut the granite and do not show evidence of mixing/mingling, were likely a separate phase of magma injection than the dyke emplaced at Sambro Head. Simply the presence of this late stage dyke emplacements could suggest multiple phases of injection with variable extents of mixing.

CHAPTER 6: CONCLUSIONS

Based upon the evidence and textures present at Sambro Head, Prospect and Peggys Cove, the following conclusions can be drawn about the extent of hybridization throughout the Halifax Pluton.

(1) Hybridization of the granitic magmas with mafic material occurred at each locality sampled in the Halifax Pluton.
(2) Variable extent of magma mixing and hybridization is reflected in the different textures recorded by the megacrysts from these three localities.
(3) Certain phases of the pluton may have experienced a higher overall average temperature.
(4) There may have been multiple phases of injection throughout the history of the Halifax pluton.

6.1 Future Work Recommendations

Future work recommendations, listed in terms of relative importance to the overall interpretation of my results, would provide further evidence towards varying extents of hybridization within the Halifax Pluton.

(1) Sample and analyze material from the granite at Sambro Head that is located at a distance from the dyke, in order to record textures that may have not been directly altered by the mafic intrusion. The evidence should show similar textures to those found at the Peggys Cove and Prospect section of the pluton.
(2) Sample and analyze material from the mafic enclaves at Prospect. The evidence should show similar textures to the crystals within the dyke at Sambro Head.
(3) Look more systematically throughout this phase of the Halifax pluton for further evidence of magma mixing and hybridization.

References

Bussy, F. (1990). The rapakivi texture of feldspars in a plutonic mixing environment: A dissolution-recrystallization process? Geological Journal, 25(3-4), 319-324. doi:10.1002/gj.3350250314

Clarke, B. D., Fallon, R., & Heaman, L. M. (2000). Interaction among upper crustal, lower crustal, and mantle materials in the Port Mouton pluton, Meguma Lithotectonic Zone, southwest Nova Scotia. Canadian Journal of Earth Sciences,37(4). doi:10.1139/e99-124

Clarke, D., & Clarke, G. (1998). Layered granodiorites at Chebucto Head, South Mountain batholith, Nova Scotia. Journal of Structural Geology,20(9-10), 1305-1324. doi:10.1016/s0191-8141(98)00067-4

Cox, R. A., Dempster, T. J., Bell, B. R., & Rogers, G. (1996). Crystallization of the Shap Granite: evidence from zoned K-feldspar megacrysts. Journal of the Geological Society,153(4), 625-635. doi:10.1144/gsjgs.153.4.0625

Downs, B. (n.d.). Geos 306, Fall 2013, The Crust. Retrieved March, 2017, from http://www.geo.arizona.edu/xtal/geos306/fall13-16.htm

Geology of the Annapolis, St. Marys Bay map area, Nova Scotia [21A; 21B East Half]; Taylor, F C. Geological Survey of Canada, Memoir 358, 1969, ; 65 pages (2 sheets), doi:10.4095/106432

Fensome, R. A., & Williams, G. L. (2001). The last billion years: a geological history of the Maritime Provinces of Canada. Halifax, NS: Nimbus Pub.

Hills, E. S. (1936). Reverse and Oscillatory Zoning in Plagioclase Felspars. Geological Magazine,73(02), 49. doi:10.1017/s0016756800087914

Home, R. J., Macdonald, M. A., Corey, M. C., & Ham, L. J. (1992). Structure and emplacement of the South Mountain Batholith, southwestern Nova Scotia. Atlantic Geology,28(1). doi:10.4138/1849

JEOL. (2012). JXA-8230 SuperProbe Electron Probe Microanalyzer (EPMA). Retrieved March, 2017, from JEOL: Global Solutions Provider for Advanced Technology: http://www.jeol.com/

Macdonald, M. A., Home, R. J., Corey, M. C., & Ham, L. J. (1992). An overview of recent bedrock mapping and follow-up petrological studies of the South Mountain Batholith, southwestern Nova Scotia, Canada. Atlantic Geology,28(1). doi:10.4138/1848

Maybank, B. (2010, October 15). Devil's Staircase - Sambro Island [The Devil's Staircase on Sambro Island, Nova Scotia]. Retrieved from https://www.flickr.com/photos/blakemaybank/5084697194

Reynolds, P. H., Elias, P., Muecke, G. K., & Grist, A. M. (1987). Thermal history of the southwestern Meguma zone, Nova Scotia, from an 40 Ar/ 39 Ar and fission track dating study of intrusive rocks. Canadian Journal of Earth Sciences,24(10), 1952-1965. doi:10.1139/e87-186

Ruffman, A., & Greenough, J. D. (1990). The Weekend dykes, a newly recognized mafic dyke swarm on the eastern shore of Nova Scotia, Canada. Canadian Journal of Earth Sciences,27(5), 644-648. doi:10.1139/e90-061

Saby, E., & Götze, J. (2004). Feldspar crystallization under magma-mixing conditions shown by cathodoluminescence and geochemical modelling - a case study from the Karkonosze pluton (SW Poland). Mineralogical Magazine,68(4), 561-577. doi:10.1180/0026461046840205

Smith, J. V. (2012). Feldspar Minerals: 2 Chemical and Textural Properties. Berlin: Springer Berlin Heidelberg.

Tate, M. C., Clarke, D. B., & Heaman, L. M. (1997). Progressive hybridisation between Late Devonian mafic-intermediate and felsic magmas in the Meguma Zone of Nova Scotia, Canada. Contributions to Mineralogy and Petrology,126(4), 401-415. doi:10.1007/s004100050259

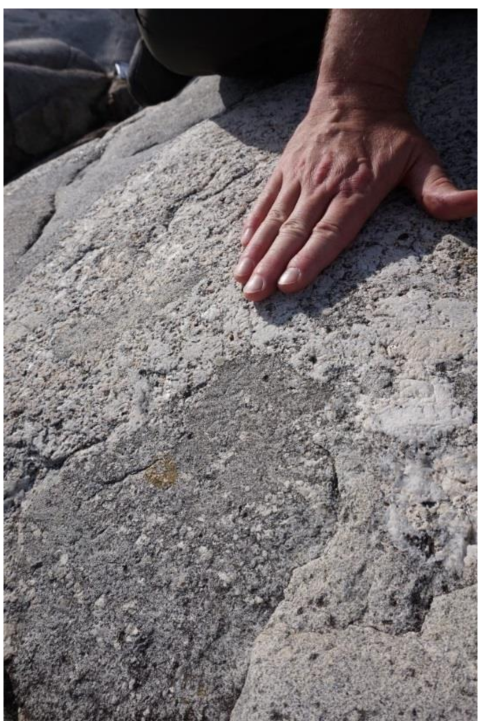
Wongus, D. (2013). Variations in barium concentrations in K-feldspar zoning, Peggys Cove and Prospect, Nova Scotia (Unpublished BSc Honours thesis). Dalhousie University, Halifax, Nova Scotia.

APPENDIX A

Field Photos

Sambro Head






Peggys Cove

Images show pegmatite veins with apalite intrusions.

Prospect

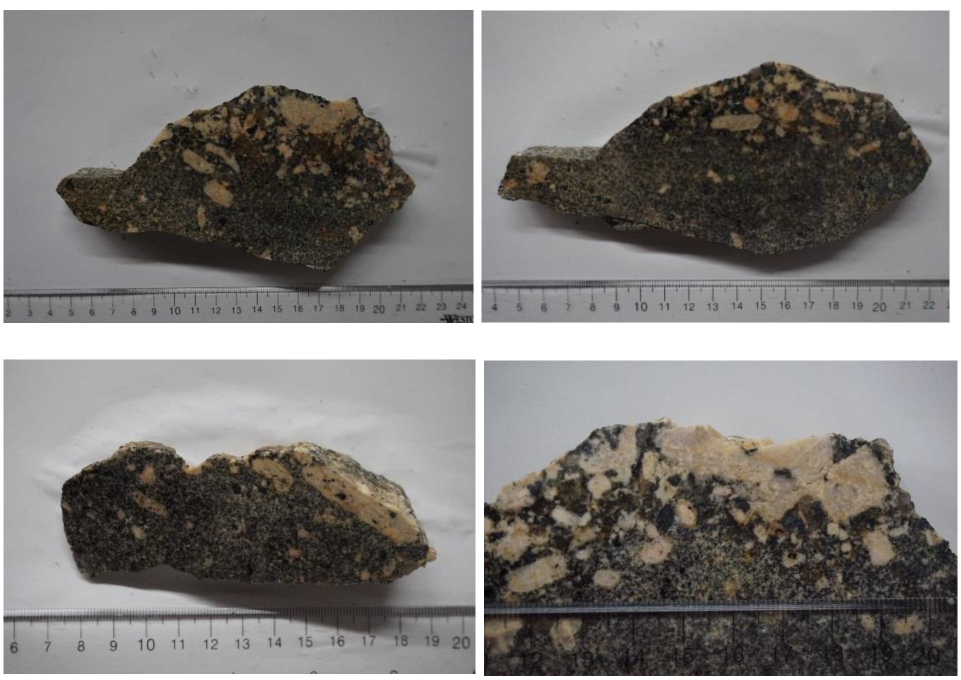
Hand Sample Photos

Sample 1

Sample 2

Sample 3

Sample 4



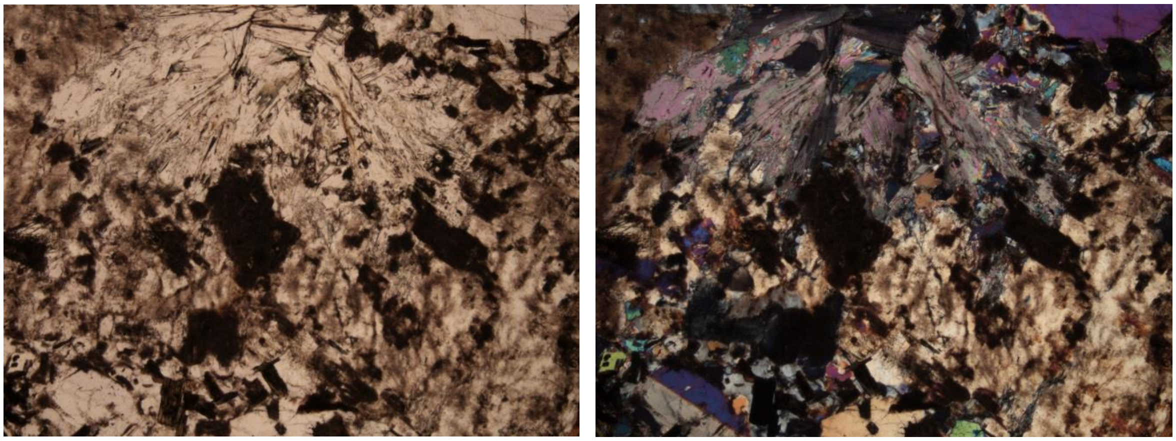
Sample 5

Sample 6

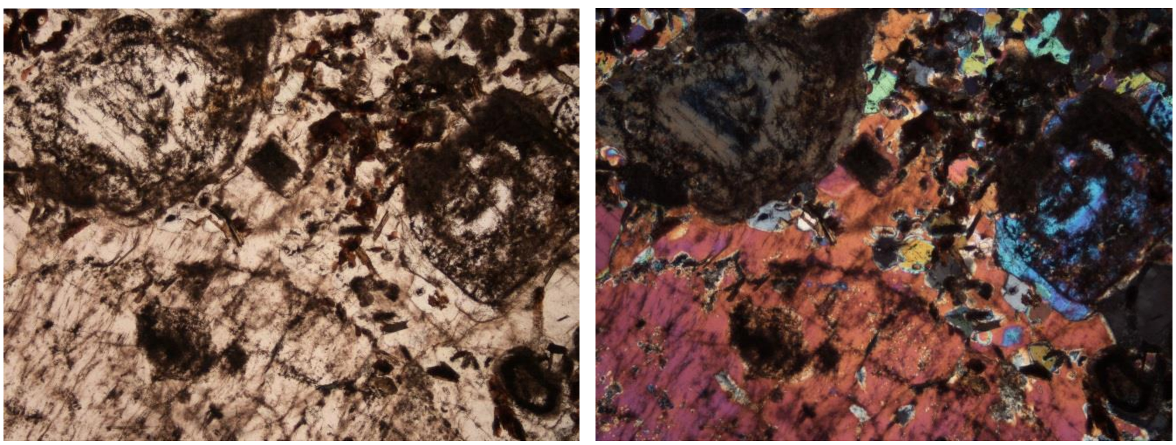

Sample 7


Petrographic Images

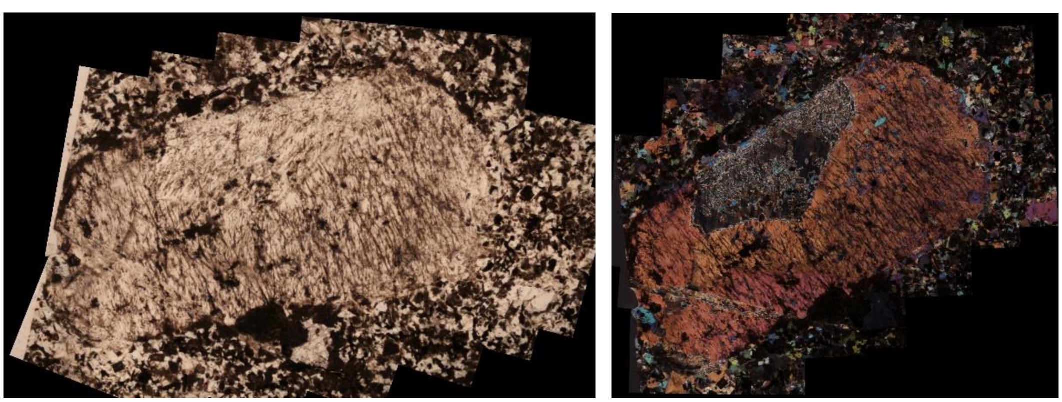
Sambro Head Sample 4-6



Sambro Head Sample 7-2

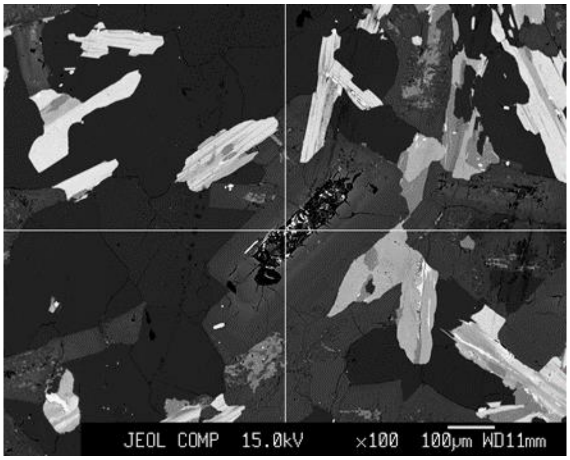


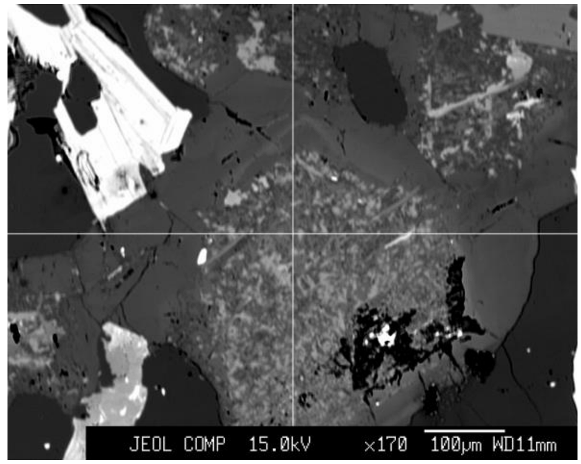
Sambro Head Sample 4-6

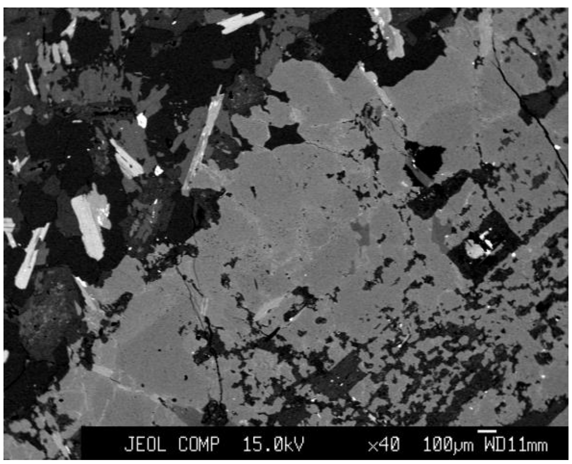


BSE Micrographs

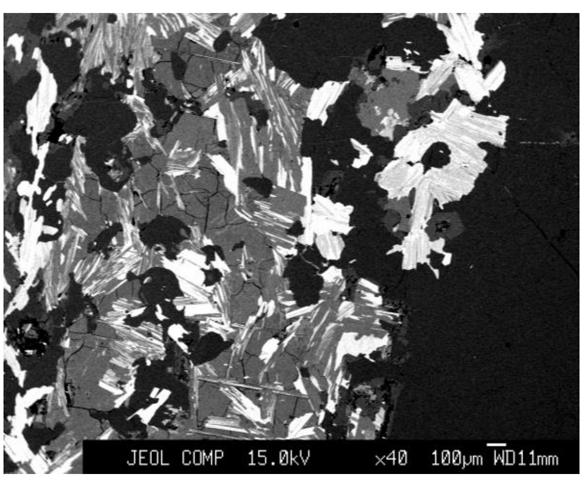
Sample 2-2

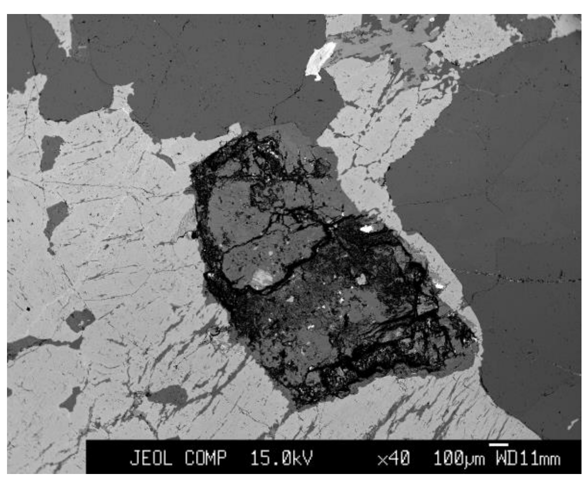


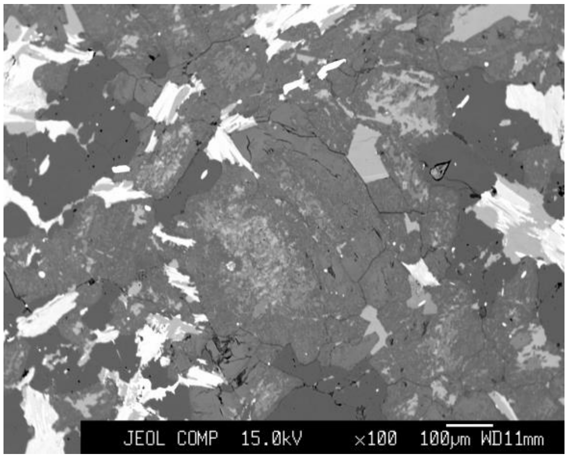


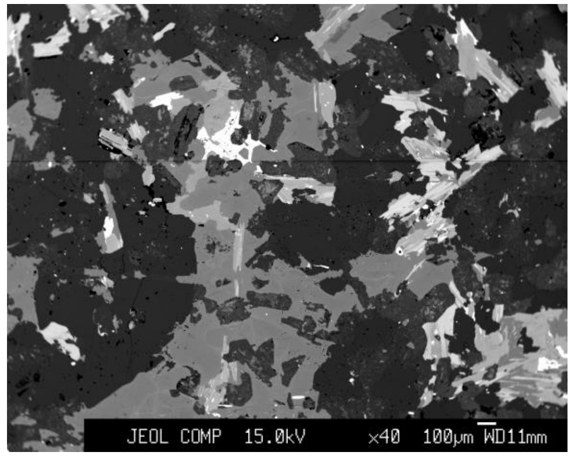


Sample 3-3



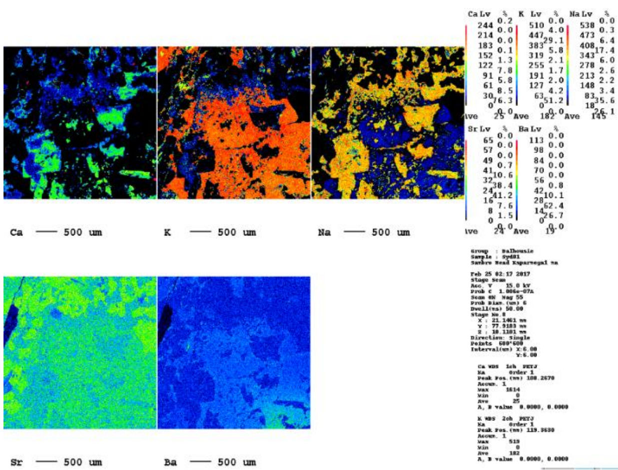


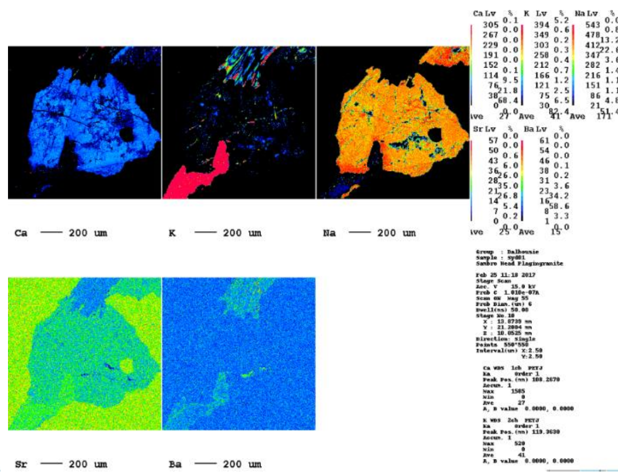


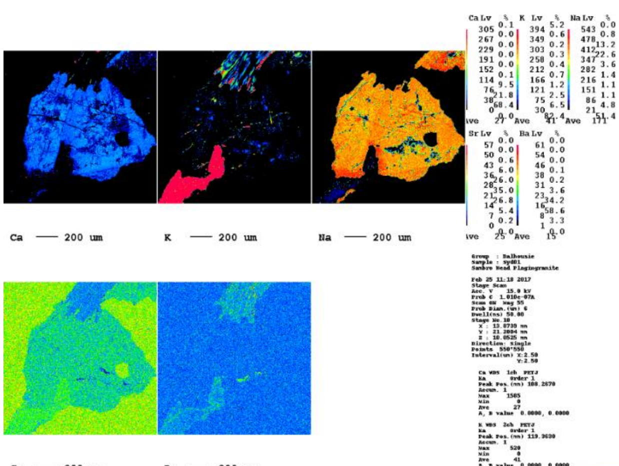


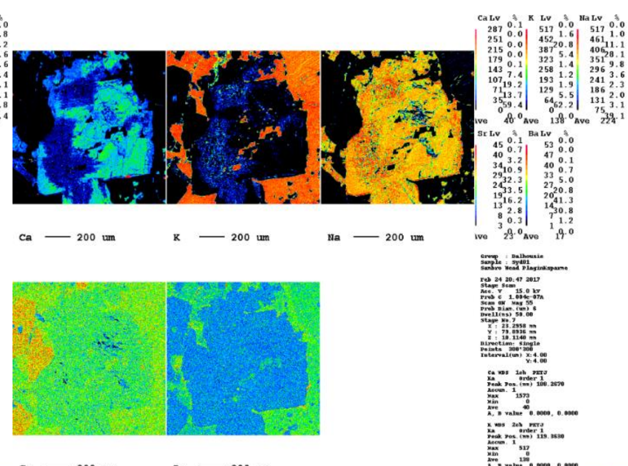
Microprobe X-Ray Maps

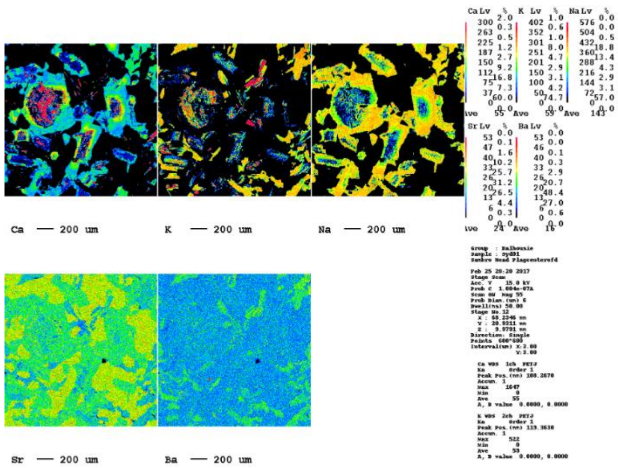
Sambro Head

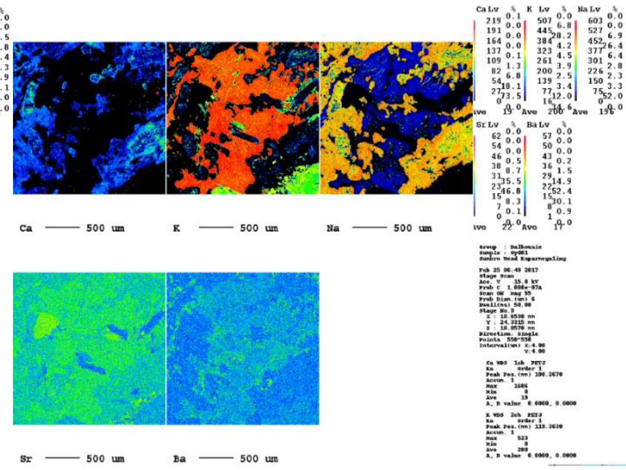


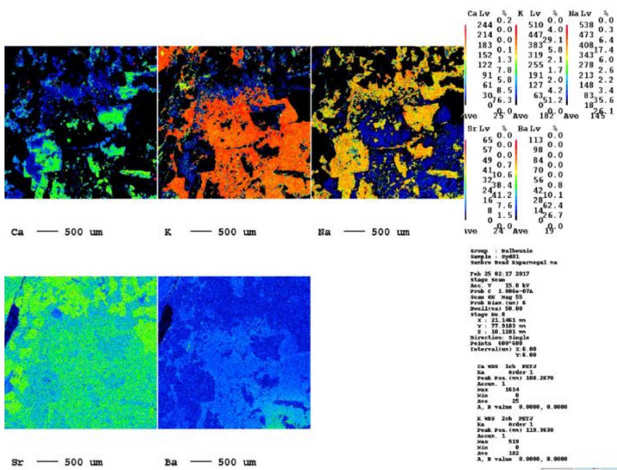


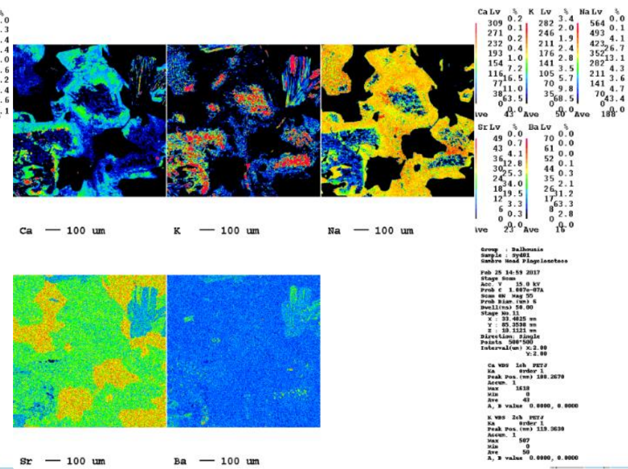




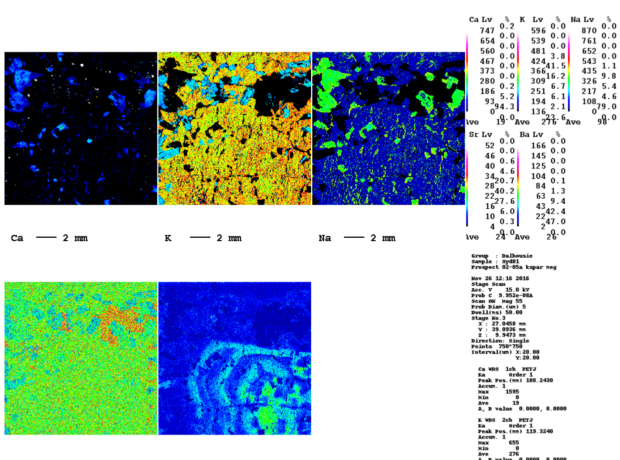

Ca — 200 um
K — 200 um
Na — 200 um
Sr — 200 um
Ba — 200 um

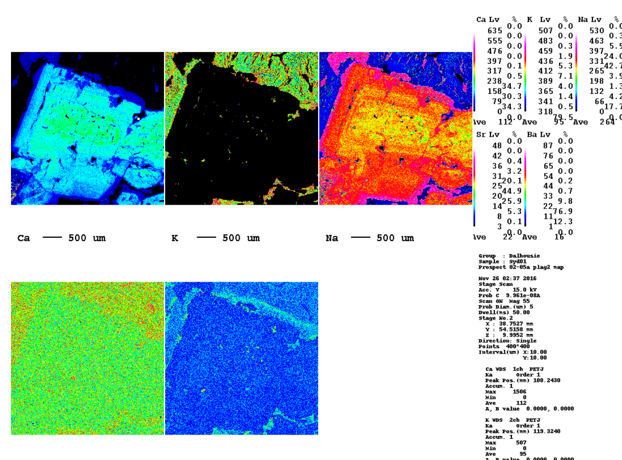

Ca — 500 um
K — 500 um
Na — 500 um
Sr — 500 um
Ba — 500 um

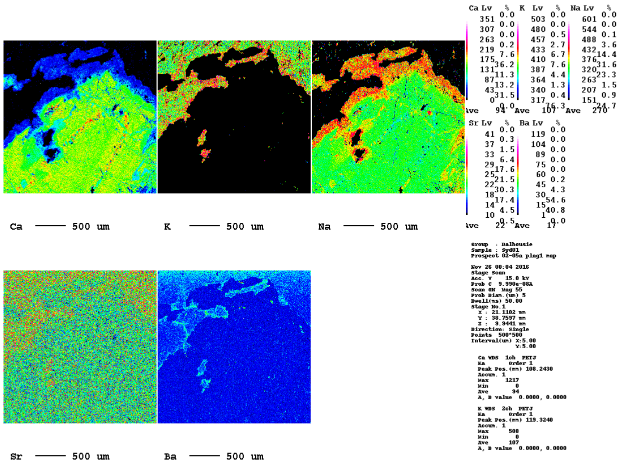

Ca — 500 um
K — 500 um
Na — 500 um
Sr — 500 um
Ba — 500 um


Ca — 100 um
K — 100 um
Na — 100 um
Sr — 100 um
Ba — 100 um

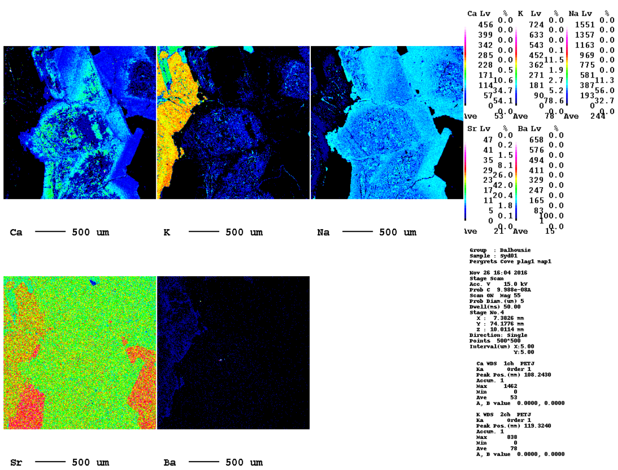
Prospect

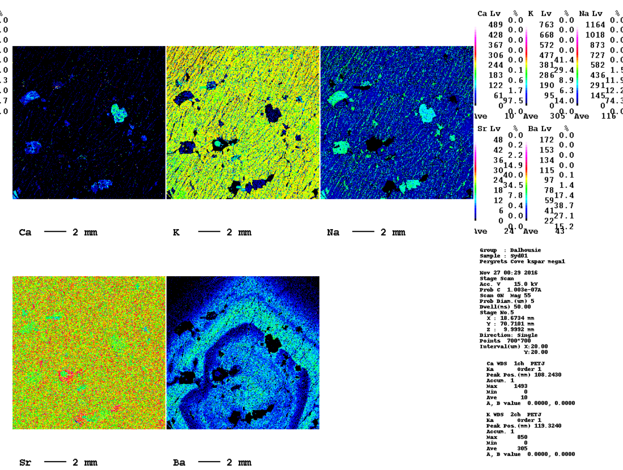

Ca — 2 mm
K — 2 mm
Na — 2 mm
Sr — 2 mm
Ba — 2 mm


Ca — 500 um
K — 500 um
Na — 500 um
Sr — 500 um
Ba — 500 um



Peggys Cove





APPENDIX B

Please refer to attached the excel sheet for the complete list of raw data collected from the microprobe.