Structural Geology of the Meguma Group

Adjacent to the Eastern Contact of the South Mountain Batholith

Neil Ross Burns

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for the Degree of Bachelor of Science

Department of Earth Sciences

Dalhousie University, Halifax, Nova Scotia

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Department of Earth Sciences
Halifax, Nova Scotia
Canada B3H 3J5
(902) 494-2358
FAX (902) 494-6889

DATE May 1, 1995

AUTHOR Neil Ross Burns

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Abstract

The purpose of this study is to recognize and evaluate structural features that may be related to the emplacement of the South Mountain Batholith. The Acadian orogeny produced folds within the Meguma Terrane with a north-east trend. The South Mountain Batholith (SMB) later intruded the terrane, but its emplacement mechanism is not completely understood. The emplacement may have had a diapiric, doming, and/or ballooning effect in some areas, and all are processes that would have deformed the surrounding country rock. In the Bedford Basin area, the Meguma Group shows several features that suggest deformation related to emplacement. An air-photo interpretation reveals a basin-shaped feature around the Bedford Syncline with a center in the area of Magazine Hill, suggestive of cross folding of regional N-E folds by pluton-related transverse folds with N-W hinges. A cross-section along the axial trace of the Bedford Syncline across the basin reveals an increasing dip toward the granite contact. This change in dip could be the result of a vertical heterogeneous simple shear imposed by the intruding pluton. Analysis of the cross-section indicates that the dipping bedding planes reflect an increase in shear strain toward the contact. These strucural features show a strong correlation to deformation expected from an active pluton emplacement; however, strain in a horizontal plane, perpendicular to the pluton boundary, is minor relative to roof-lifting suggested by the cross-section.

Keywords: Meguma Group, South Mountain Batholith, emplacement, deformation, shear strain, extension, granitoid, cross-section

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CHAPTER 1 INTRODUCTION

1.1 Emplacement Mechanisms of Granitoid Plutons

A plutonic body replaces the rock that formerly occupied that space. Emplacement of a pluton can occur in a variety of ways, ranging from a passive emplacement which causes very little deformation of the surrounding rocks, to an active emplacement which causes intense deformation of the surrounding rocks.

When a melt forms at depth it has a lower density than the surrounding rock. This lower density results in a gravitationally unstable condition that results in upward migration of the melt. As the melt rises it expands because of the decreasing confining pressure, and it continues to rise until it reaches a physical equilibrium with the surrounding rock. A competent overlying unit can stop the migration of the melt. The melt may then crystallize at this level. Under other conditions, the melt may even reach the surface. Some of the factors that affect the movement of the melt are the temperature of the country rocks, depth, pressure, viscosity of the melt (especially the amount of crystallization), and composition of the melt (particularly its water content).

Cauldron subsidence, stoping, and zone melting are three types of passive emplacement mechanisms (Fig. 1.1). The process of stoping removes overlying blocks of country rock which sink to the bottom of the magma chamber (Clarke 1992). Cauldron subsidence is merely a larger version of this process, involving downward displacement of a large block. Zone melting is a slow process in which the rocks overlying the magma

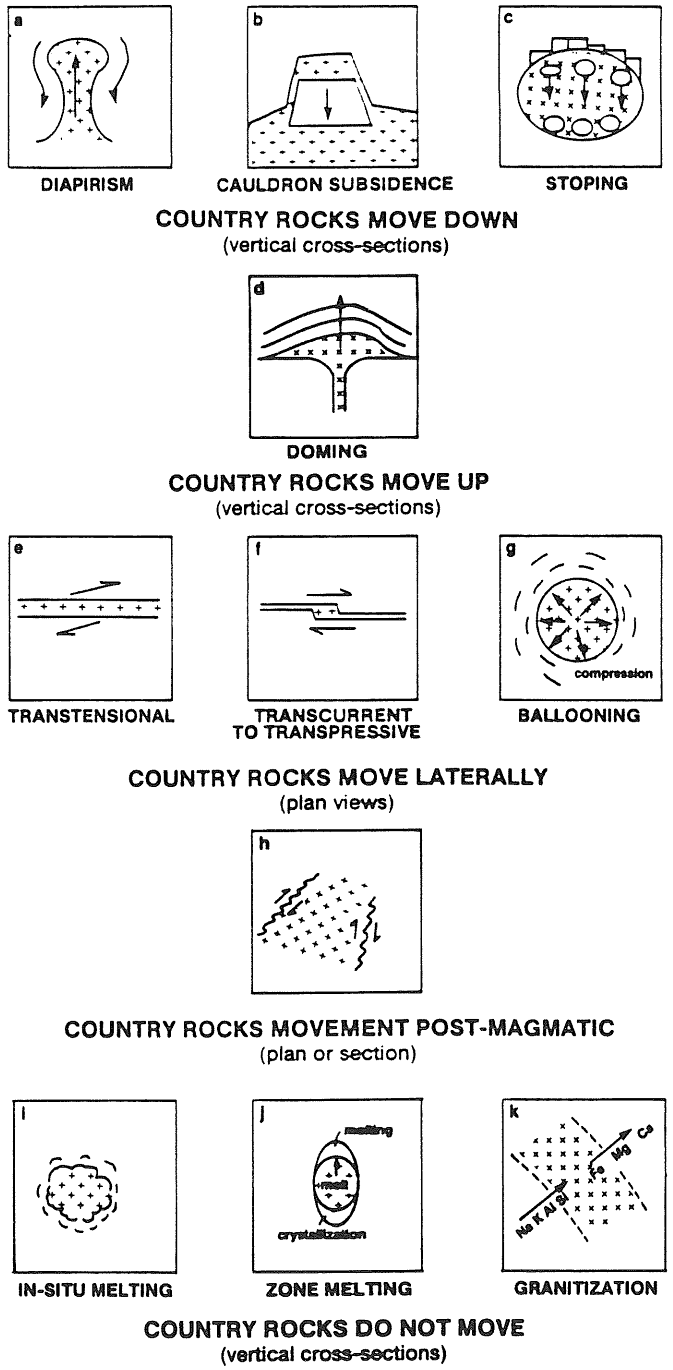

Figure 1.1 Styles of ascent and emplacement of granitic bodies (from Clarke 1992).

chamber partially melt, and instead of the volume of melt becoming larger, it is roughly counterbalanced by crystallization on the bottom of the magma chamber (Clarke 1992). These processes allow the melt to move upwards without deforming the surrounding rocks.

Diapirism, doming, and ballooning are all active types of emplacement that deform the surrounding country rock (Fig. 1.1). Diapirism involves the formation of a melt which rises because of its lower density, and takes on a mushroom shape. As the diapir rises it deforms the surrounding country rock by forcefully pushing it aside or upwards (Clarke 1992). The initial movement of a diapir normally may not be very far, but subsequent injections of magma can continue its upward ascent (Clarke 1992). If the melt encounters a very resistant overlying layer at shallow levels, the buoyant forces of the rising melt may be large enough to push up the rock but not break through it (Clarke 1992). This phenomenon is known as doming. If magma is being pumped from below into the chamber causing it to expand, then ballooning results (Clarke 1992). This inflation deforms the country rocks immediately surrounding the pluton.

The South Mountain Batholith (SMB) is a very large granitoid intrusion. It has a thickness of ca. ~5 km along its perimeter, whereas at its center in New Ross its thickness may exceed ~25 km (Abbott 1989). This overall shape would appear to give it a geometry comparable to that of a diapir, thus the intrusion of the SMB may have deformed the surrounding Meguma. On the other hand the intrusion may be diapir-like at New Ross and sill-like around its margins.

1.2 Contact Metamorphism

The intrusion of a plutonic body into country rock can produce more than just structural deformation in the country rocks. Heat transfers from the intrusive body to the cooler surrounding rock, and the change in temperature of the country rocks may produce recrystallization of some of the minerals within the rock, or it may promote metamorphic reactions resulting in the formation of new minerals. A sequence of metamorphic zones occurs away from the intrusion reflecting the decreasing temperature.

To overcome the problem of correlation of P-T conditions between zones based on different rock types, Eskola (1915) introduced a scheme of metamorphic facies. These facies are a broad representation of P-T subdivisions. Facies are defined as a range of P-T conditions over which a particular common mineral assemblage or range of mineral assemblages are stable (Yardley 1989). Figure 1.2 shows the fields of the various facies under the conditions of pressure and temperature. Contact metamorphism normally occurs in the upper levels of the crust and, therefore, it occurs at high temperatures and low pressures. The typical facies of contact metamorphism are the albite-epidote hornfels, hornblende hornfels, pyroxene hornfels, and sanidinite facies.

1.3 Objective and Scope

The study area is located in the vicinity of the Bedford Basin, near Halifax, Nova Scotia. It consists of outcrop areas of the Meguma Group beginning near Bayers Lake on

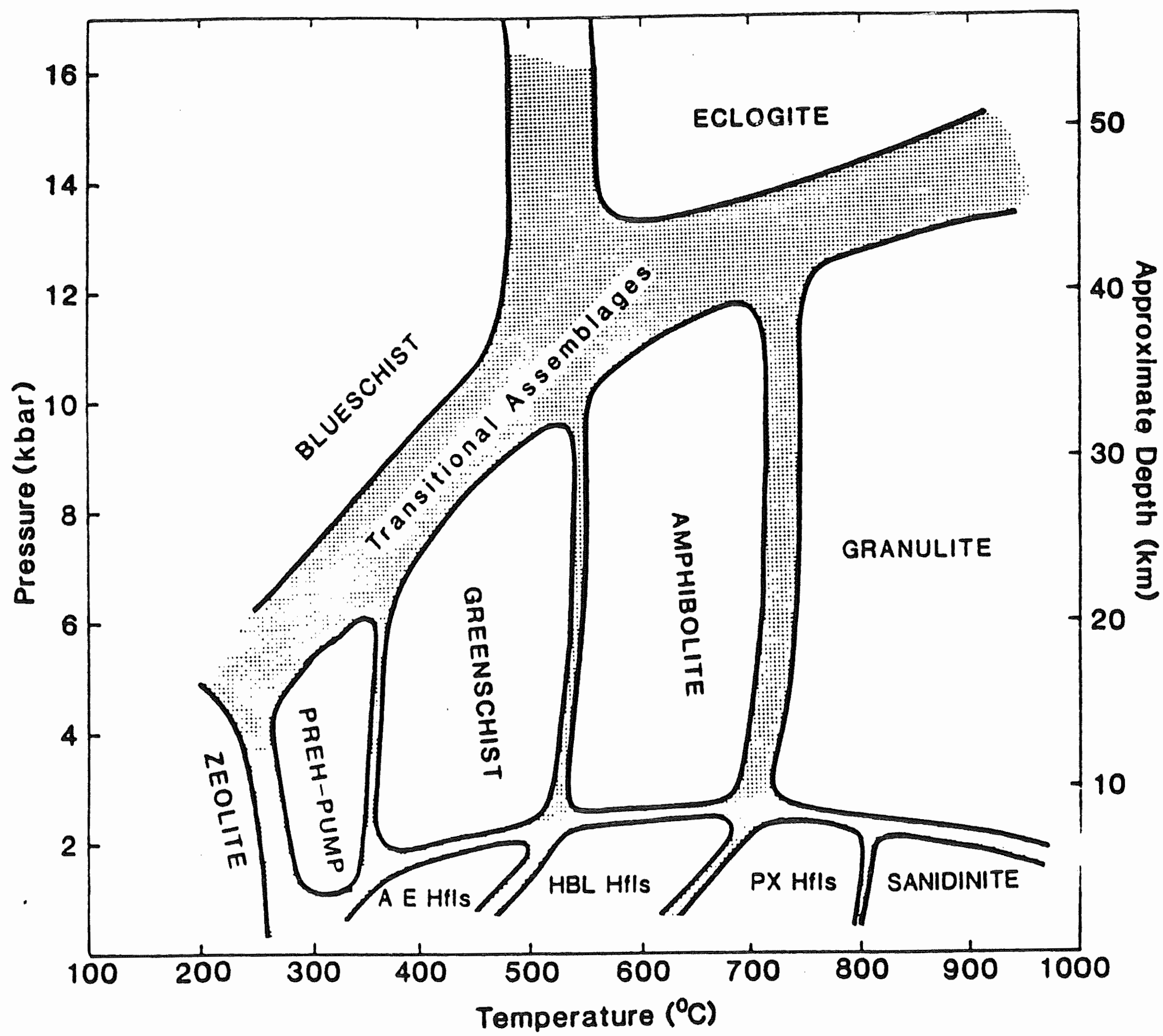

Figure 1.2 Pressure-temperature diagram showing the fields of the various metamorphic facies (from Yardley 1989).

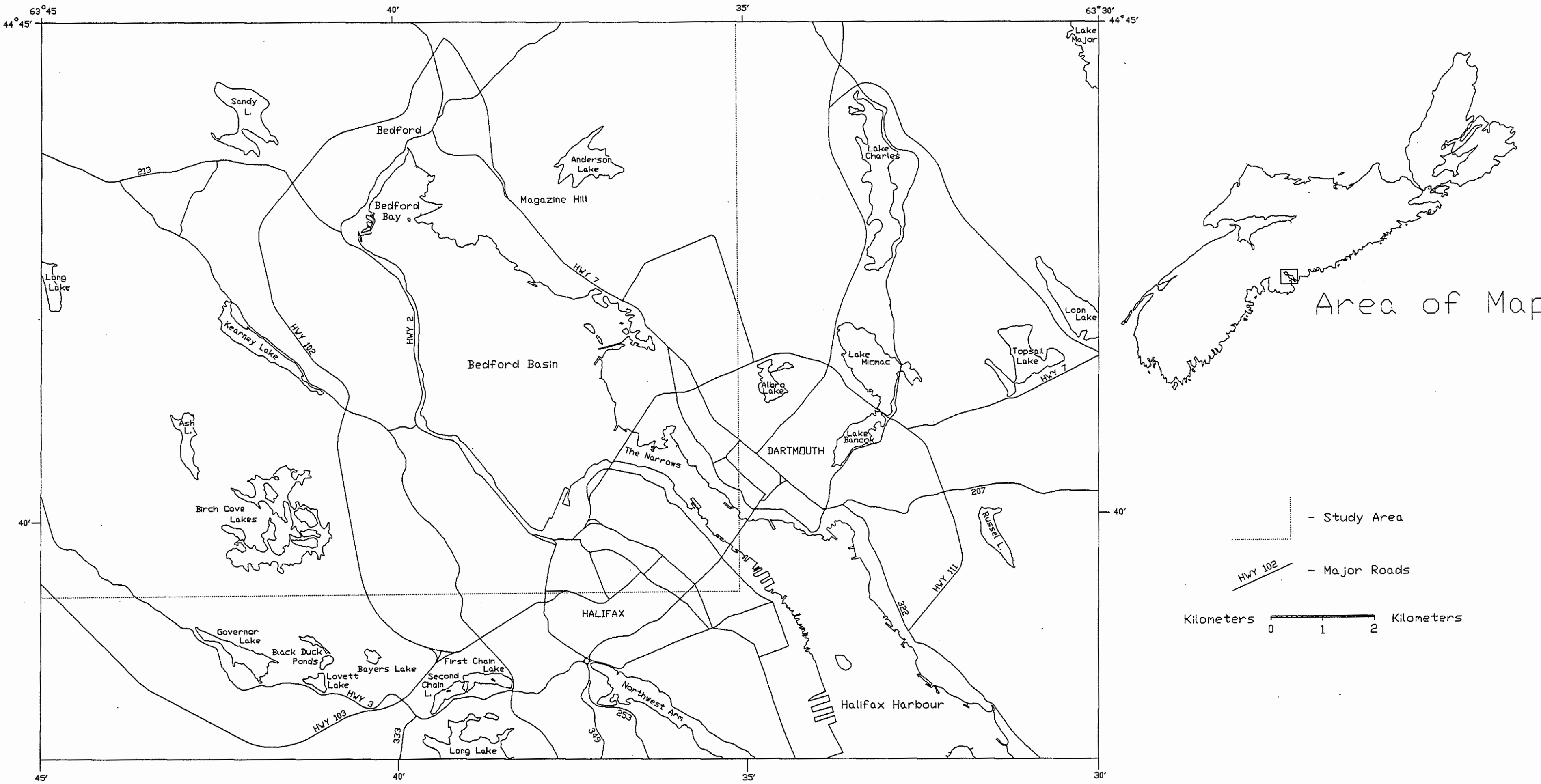

Figure 1.3 Location map of study area.

Highway 102 and continuing north around the Basin beyond Magazine Hill (Fig. 1.3). The area is bounded on the west by the SMB, the largest granitoid intrusion in the Appalachian orogen (180 km long by 50 km wide), which occupies almost half of southwest Nova Scotia (Abbott 1989).

This thesis examines aspects of the structural geology of the Cambrian - Ordovician metasediments of the Meguma Group in the contact zone of the SMB in a restricted region ca ~5X 10 km in the Bedford area. The regional trend of folding within the Meguma is basically consistent throughout and is cross-cut by the SMB. However, a narrow transverse (perpendicular to the regional trend) anticline and syncline that are adjacent and parallel to the intrusion contact (Faribault 1908), and a larger basin-shaped feature within the Bedford syncline northeast of Bedford Basin, suggest some syn-emplacement deformation. If the SMB deformed the country rock, then the narrow transverse folds could be an indication of such an event. Likewise, the large basin-like feature could be the result of refolding a regional syncline. The purpose of this thesis is to determine whether these transverse features are related to the emplacement of the SMB, and, if so, to evaluate them with respect to possible emplacement mechanisms of the SMB.

This investigation relies on a compilation of existing structural data and an acquisition of new data on bedding (S_0) and cleavage (S_1), as well as an air-photo interpretation of large scale structures. Methods of data analysis include conventional stereographic plots, and computer mapping. The investigation deals solely with structural features obtainable from field analysis without the use of thin sections.

1.4 Organization

Chapter 2 describes the geological setting from the Late Devonian to the present to determine the history of the rocks within the study area. Chapter 3 presents the data (collected and compiled) and displays it in a number of figures. Chapter 4 interprets the data to determine if evidence of a deforming pluton emplacement exists. Chapter 5 contains the conclusions of the investigation and a suggestion for further work.

CHAPTER 2 GEOLOGICAL SETTING AND GENERAL GEOLOGY

2.1 Introduction

This chapter describes the rocks within the Meguma Group on local and regional scales. The Bedford Basin area is underlain by rocks of the Goldenville and Halifax Formations, both members of the Meguma Group. The Meguma Group is a major bedrock component of the Meguma terrane. The Acadian Orogeny deformed and metamorphosed the Meguma terrane, and later plutonism within the Meguma terrane thermally metamorphosed the Meguma Group. Deformation continued during and after pluton emplacement.

2.2 Regional Geology

The Canadian Appalachians consist of deformed Paleozoic rocks in Newfoundland, Nova Scotia, New Brunswick, and Quebec south of the St. Lawrence River (Keppie 1993). They are the product of subduction, continental collision, and transform movements extending from the Ordovician to the Carboniferous. The major orogenic events involved are the Taconian (Ordovician), a Salinian event, Acadian (Devonian), and Alleghanian (Carboniferous) orogenies. Of these, the Acadian and Alleghanian dominate mainland Nova Scotia.

The Paleozoic structures are the result of the accretion of terranes within the Appalachians. The term terrane was adopted in the early 1980s (Coney et al. 1980; Williams and Hatcher, 1982). In the Canadian Appalachians the terms "terranes" and "zones" are sometimes used interchangeably (Williams et al. 1972; Williams 1978;1979). A terrane is an internally homogeneous geologic province, with features that contrast sharply with those of adjacent provinces. The terrane boundary is normally a fault (Williams and Hatcher 1982). Major terranes, or zones, within the Canadian Appalachians are generally agreed to consist of: 1) the North American terrane or Humber Zone; 2) the Dunnage Zone which consists of the Notre Dame and Exploits subzones (Williams et al 1988); 3) the Gander terrane or Zone; 4) the Avalon Composite terrane; and 5) the Meguma terrane (Keppie 1993).

Nova Scotia consists of the Avalon, Humber, and Gander terranes in the north and Meguma Terrane in the south, separated by the Cobequid - Chedabucto Fault System or Minas Geofracture (Fig. 2.1). The Avalon and Meguma terranes both lie east of the passive margin and are, therefore, both suspect (unknown paleogeography) (Williams and Hatcher 1983). The Meguma terrane has no definite linkage with the Avalon terrane, or any other Appalachian terrane, until overlapped by Carboniferous sedimentation after accretion (Williams and Hatcher 1983). The batholithic intrusions of the Meguma terrane are also distinct from those of the bordering Avalon Terrane (Clarke et al 1980). The Meguma terrane probably docked when the supercontinent, Pangea, formed and the mechanism of accretion most likely involved transcurrent faulting and transpression (Williams and Hatcher 1983). Rifting occurred during the Triassic, separating the continents again, leaving the Meguma Terrane behind.

2.3 Meguma Terrane

The Meguma lithotectonic terrane consists of a variety of different rock types. The oldest rocks in the terrane are the Cambrian-Ordovician psammites and pelites of the Meguma Group. Overlying the Meguma Group are the Silurian-Devonian New Canaan, Kentville, White Rock, and Torbrook Formations, consisting of mixed volcanic, volcaniclastic, and metasedimentary rocks (MacDonald et al. 1992). The next younger rocks are the peraluminous granites, including the SMB, that were emplaced ca. 370-375 Ma (Clarke et al. 1993). The SMB has thirteen mappable plutons defined on the basis of cross-cutting relationships of regional lithological-petrographic and/or chemical zonation (MacDonald et al. 1992). These plutons are categorized into two groups: older Stage 1 plutons dominated by biotite granodiorite and biotite monzogranite; younger Stage 2 plutons dominated by leucomonzogranite and leucogranite (Horne et al. 1992). The Horton Group consists of coarse clastic terrestrial sedimentary rocks of Tournaisian age (Bell and Blenkinsop 1960; Howie and Barss 1975) that overlie the granite.

At the present time two theories can explain granitoid plutonism. One is that crustal thickening resulting from the Acadian Orogeny may have produced melting that formed the intense plutonism in the Meguma Terrane (Clarke et al. 1993). The other is that mafic magmatism may have contributed heat necessary to produce the melting that resulted in the granite plutonism (Tate 1995). As previously stated, the age of this plutonism has been measured at 375 Ma (Clarke et al 1993).

Along with this major plutonism, an ortho- and paragneiss complex, near Liscomb, with associated gabbroic intrusions (Giles and Chatterjee 1986, 1987) pierces the Meguma Group metasedimentary rocks. The emplacement of the complex has been dated, from geochronological studies ($^{40}Ar/^{39}Ar$) of cooling of the gneissic rocks, at approximately the same time as the major granitoid intrusions (Kontak and Reynolds 1994). The Liscomb gneisses are chemically distinct from the Meguma Group rocks and, therefore, the gneisses had a different protolith, presumably lower crust (MacDonald et al 1992). A number of dykes containing exotic gneissic and (meta) plutonic xenoliths, near Tangier, have been suggested to have been emplaced at the same time as the Liscomb gneisses (Kempster et al 1989). Detailed petrological and geochemical studies of a suite of granulite xenoliths from one of the dykes (Chatterjee and Giles 1988; Eberz et al. 1988, 1991) suggested that the xenoliths represent material from the Avalon Terrane that was thrust beneath the Meguma Terrane. These rocks are the only clues as to the nature of the lower crustal rocks beneath the Meguma Terrane.

2.4 Meguma Group

The Meguma Group consists of metasediments of Cambrian-Ordovician age involving two members, the Goldenville and Halifax Formations. The older Goldenville is a sandy flysch that is at least 7 km thick. The Halifax Formation, which is a shaly flysch, conformably overlies the Goldenville Formation. Together the two formations are at least 13 km thick. Graptolites at the base of the Halifax Formation give it a maximum age of Late Cambrian (Cumming 1985). Depositional environments of these formations are marine. The sandy character of the Goldenville reflects a near-shore environment, whereas the black shale character of the Halifax reflects a much deeper anoxic environment of deposition. Schenk (1981) compared the depositional environment of the formation to that of a deep-sea fan complex grading upward into slope and outer-shelf environments.

2.5 Contact Metamorphism

The intrusion of the SMB resulted in contact metamorphism of the Meguma Group that is only slightly above the regional greenschist and amphibolite facies (Taylor 1967). Effects of this contact metamorphism include silicification and porphyroblast growth of andalusite (chiastolite), cordierite, and rarely alkali feldspar. These minerals occur predominantly in the pelitic rocks (MacDonald and Horne 1987).

2.6 Deformation Within The Meguma Terrane

The Acadian Orogeny occurred during the Mid-Late Devonian (Keppie and Dallmeyer 1987; Muecke et al. 1988). This event deformed and metamorphosed the Meguma Terrane, affecting the Meguma Group and the New Canaan, Kentville, White Rock, and Torbrook Formations.

Lateral shortening during the Acadian Orogeny produced upright folds, axial planar, spaced, and slaty cleavage (Henderson et al 1986). The folding produced anticlines and synclines that have a regional northeast-southwest trend (Figure 2.1). The folds possess cylindrical forms that continue for tens of kilometers, and have conical terminations (Henderson et al 1986).

Several features indicate that the Meguma terrane experienced moderate intermittent or progressive transpression (continuing after the Acadian Orogeny) in a northwest direction during the Late Devonian to Permian. These transpressive features

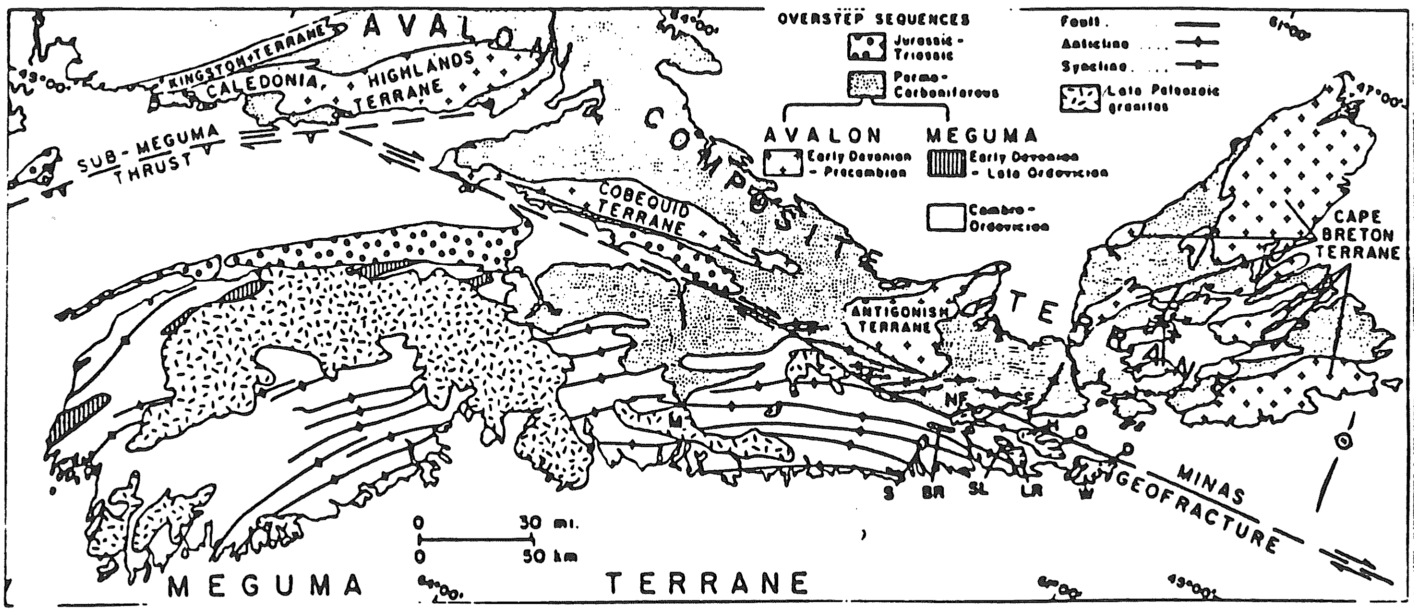

Figure 2.1 Simplified geological map of the Meguma, Avalon, Dunnage, and Gander Composite Terranes in the mainland Canadian Appalachians (after Keppie 1987).

include: 1) a strike-slip movement along the Cobequid-Chedabucto and Hollow fault systems (Eisbacher 1969; Webb 1969; Keppie 1982; Yeo and Ruixiang 1986; Mawer and White 1987); 2) a regional northwest shortening of Upper Paleozoic sedimentary basins (Lajtai and Stringer 1981; Nance 1987; Boehner 1991), which included thrusting, folding, and strike-slip faulting; and 3) a northeast-trending dextral shearing that occurred from the Late Devonian to Permian (Dallmeyer and Keppie 1987; Kontak et al. 1989).

2.7 Synplutonic Deformation

Although the plutonism post-dated the folding within the Meguma Terrane, a significant stress regime, possibly related to the late Paleozoic transpression, may have continued and thus affected the emplacement of the granite (Horne et al. 1992). This stress during emplacement is demonstrated by two features: 1) the regional pattern of joints, many of which host granite-related veins; and 2) the orientation and shape of the internal (stage 2) plutons of the SMB that mimic the trend of joints (Horne et al. 1992; MacDonald et al. 1992).

The two orientations of the pluton boundaries, referred to above, are northwest and northeast. The northwest direction is basically parallel to the direction of maximum stress within the regional stress field initiated with the Acadian orogeny. This orientation may be the result of extension in the σ_3 direction (Fig. 2.2) and plutons oriented in this direction are of the Stage 2 type (Horne et al. 1992). Some of these plutons have a lateral pull-apart geometry similar to the transcurrent to transpressive model (Fig. 1.1). Stage 1 plutons have a northeast trend in pluton shape and megacryst alignment. This trend is parallel to the regional structural trends in the country rocks. The trend may reflect

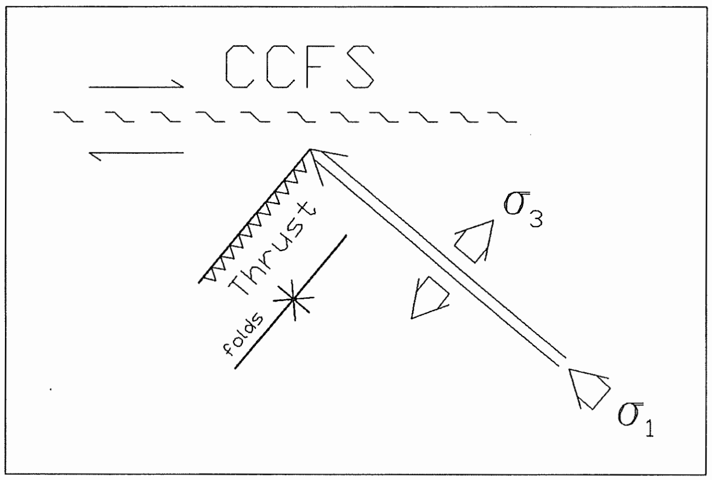

Figure 2.2 Schematic diagram of the general NW-transpressional stress regime affecting the Meguma terrane during the Late Paleozoic (CCFS- Cobequid-Chedabucto Fault System) (from Eisbacher 1969).

internal deformation from stress related to viscous flow of the magma during emplacement (Abbott 1989), or alignment from synemplacement shearing in an active stress regime (Horne et al. 1992).

Although the initial deformation that caused the Acadian folding and cleavage (Late Devonian) pre-dates the intrusion of the granitoids, deformation did not cease at that time and, as described above, may have continued during and after the emplacement of the granitoids. Evidence of flexural slip (Horne and Culshaw 1993) within the Halifax Formation occurs along the railway tracks in the south end of Halifax, and along the coast at the Ovens. Movement is apparent from slickensides and the offset of bedding-discordant markers (Horne and Culshaw 1993). Extensional shear fractures related to flexural slip that truncate cordierite porphyroblasts related to the contact aureole of the SMB (Horne and Culshaw 1993) prove the presence of deformation during, or more likely after, the emplacement of the SMB.

The deformational effects of emplacement of the SMB are not well documented. Regional maps do not show obvious large scale structures related to emplacement.

2.8 Summary

Continental collision, during the Acadian Orogeny, produced cleavage and folding within the Meguma terrane. Metamorphism following crustal thickening related to this collision, or mafic magmatism may have caused the plutonism that formed the SMB. Deformation did not entirely terminate before the emplacement of the SMB and, therefore, may have affected its emplacement. The SMB did not have a large structural effect on the surrounding rock. Possible structures resulting from granite emplacement are the subject of the next chapter.

CHAPTER 3 DATA

3.1 Introduction

This chapter describes the minor and major structures of the study area. Minor structures include bedding (S_0) and cleavage (S_1) in both the Halifax and Goldenville Formations. Major structures include large-scale folds that follow the regional north-east trend, transverse folds that parallel the granite boundary, and a basin-like feature that is centered around the Bedford Syncline. These structures were studied to determine the extent of deformation resulting from the intrusion of the SMB. A cross-section along the hinge trace of the Bedford syncline (the long axis of the basin) perpendicular to the contact of the pluton forms part of the test of the hypothesis that the intrusion of the pluton is the cause of the deformation that formed the basin and transverse folds.

3.2 Minor Structures

Attitudes of bedding (S_0) and cleavage (S_1) are the principal data in this study within the Halifax and Goldenville Formations of the Meguma Group. The strike and dip of selected S_0 and S_1 measurements corresponds to major structural trends. The original map (Fig. 3.1) has a scale of 1:25 000 (Appendix A). The figure shows new data, data compiled principally from Faribault (1908), and to a lesser extent, data extracted from class work by members of 1994 ESC 2110 (Halifax area). This material is compiled in a Fieldlog data-base. This database contains UTM coordinates of 188 stations from Faribault (1908), each containing S_0 data in the form of strike and dip measurements as

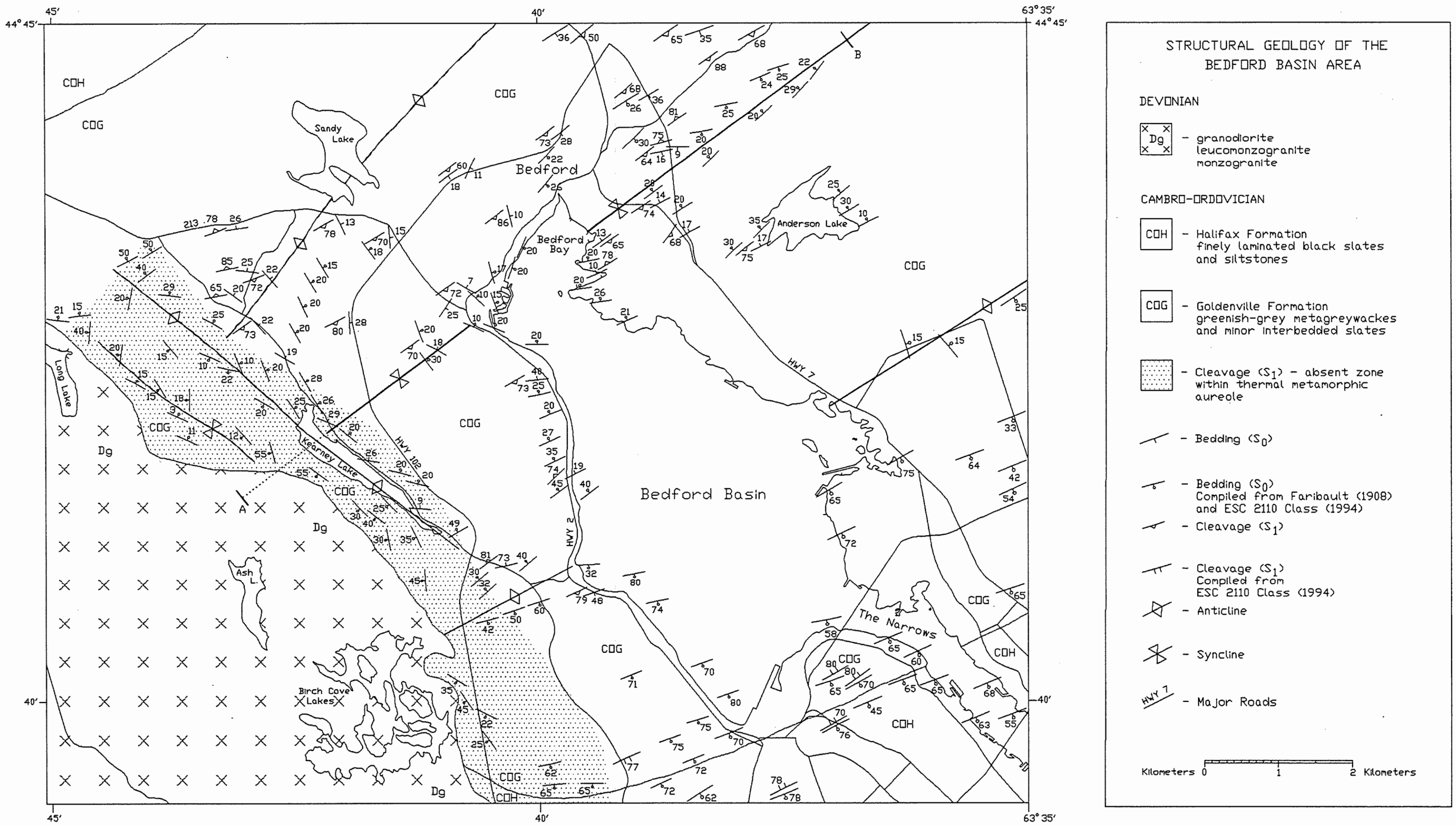

Figure 3.1 Map of study area containing raw S_0 and S_1 data (geology compiled from Donahoe 1989; Faribault 1908; MacDonald 1987).

well as UTM coordinates of 37 stations collected by the author, each containing S_0 and S_1 data in the form of strike and dip measurements (Appendix A). Measurements of S_0 were calculated from the projection of apparent dips on a stereonet to obtain the true strike and dip since true exposed bedding surfaces are rare.

The Goldenville Formation is massive, with thick, relatively featureless, layers of sandy quartzite (1-2m thick). Recognition of S_0 is difficult except where thin laminations (2-10 cm) of finer sediment occur. Some horizons display cross-bedding, thereby also allowing recognition of S_0. Cleavage is not obvious everywhere within the coarse sandy units of the Goldenville, but is present in finer grained muddy lenses within the quartzite. Cleavage maintains a steep dip axial planar to the regional north-east trending folds (Fig. 3.1). Other small scale features are rare; for instance, outcrop-scale folding does not occur within this unit.

3.3 Major Structures

Figure 3.2 is an air-photo interpretation of the study area constructed from the tracing of ridges that represent S_0 strike in the Goldenville Formation. The interpretation illustrates the large-scale geometry of the structures.

The pattern of S_0 on the air photo interpretation reveals an elongate basin with a center in the area of Magazine Hill, here named the Magazine Hill Basin (MHB). The MHB has an approximate length, in the northeast-southwest direction, of 9 km, and width of 5 km. The basin is symmetrical about a NE-SW axis (hinge trace of the Bedford Syncline) and a NW-SE axis. Stereographic projection of bedding measurements (S_0 in

Fig. 3.2) shows that the bedding is somewhat dispersed from the tight girdle expected for a cylindrical fold.

A transverse anticline and syncline lie perpendicular to the hinges of regional folds and parallel to the contact of the granite close to the contact. These folds are also approximately parallel to the NW-SE symmetry axis of the MHB, and their combined approximate width is 1.6 km. The transverse folds lie within a band that does not contain cleavage (S_1-absent zone) and lies within the thermal metamorphic aureole of the SMB.

3.4 Cross-Section

An important objective is to determine if the MHB is a moderately canoe-shaped fold formed during one event (periclinal fold), or a structure formed by refolding an upright horizontal fold by a second upright horizontal fold with a hinge at 90° to the hinge of the first fold (type 1 fold interference pattern) (Ramsay 1967). In the later case, the structure may have formed by refolding of regional folds along the NW-SE axis as result of pluton emplacement. The construction of a cross-section (Fig. 3.3) along the NE-SW axis of the MHB (A-B, Fig. 3.2) should reveal any change in structure close to the pluton. The cross-section was constructed from S_0 measurements that lie close the line A-B in Figure 3.1. These measurements were projected back to the section line A-B on which apparent dips were calculated. These apparent dips were then drawn on the vertical section plane. The cross-section shows the transverse syncline and anticline and the more gently dipping beds of the MHB. The beds dip more steeply in the south-western end of the section than in the northern-eastern end of the section. A general decrease in apparent

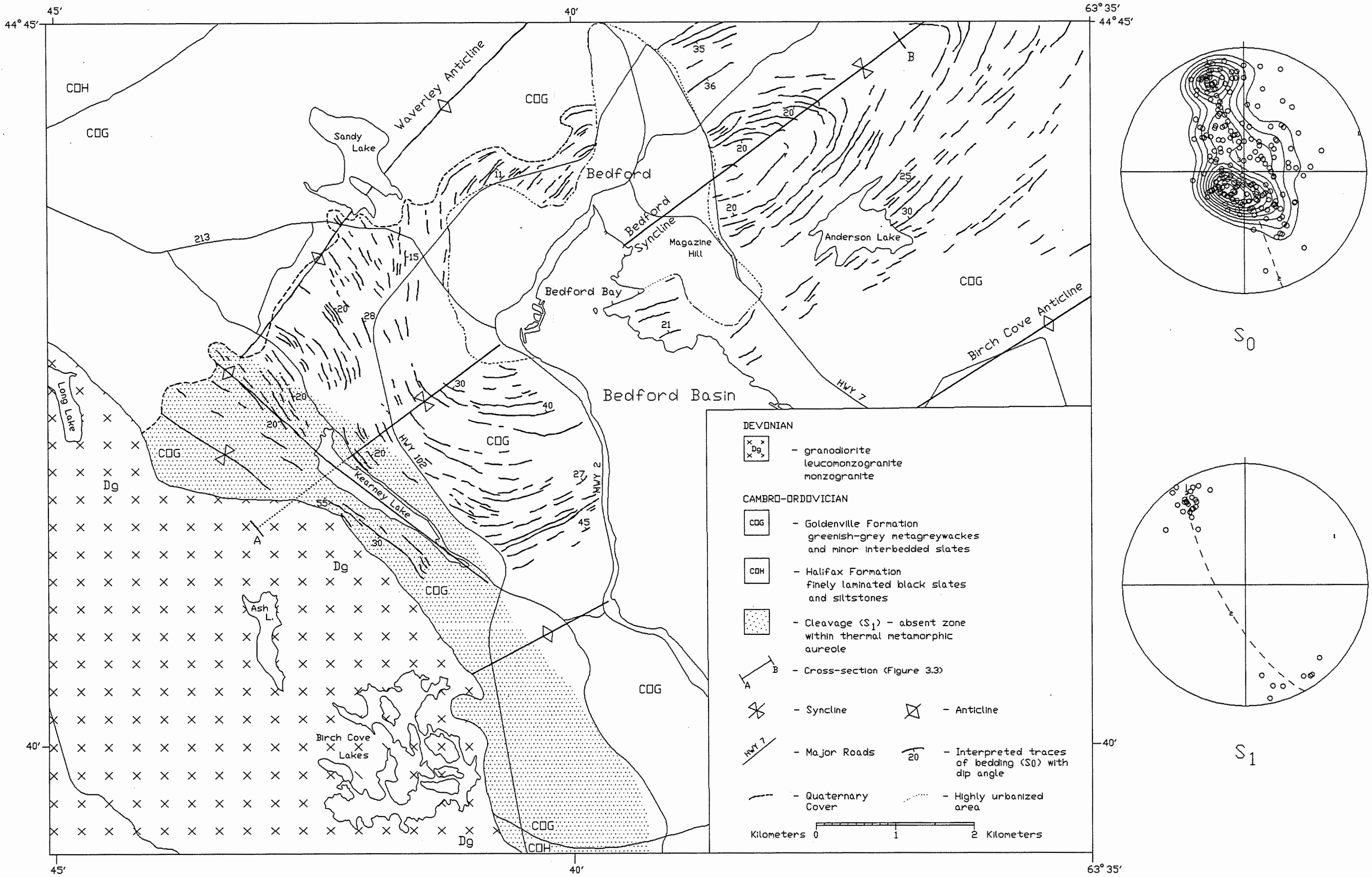

Figure 3.2 Air-photo interpretation of the Magazine Hill Basin.

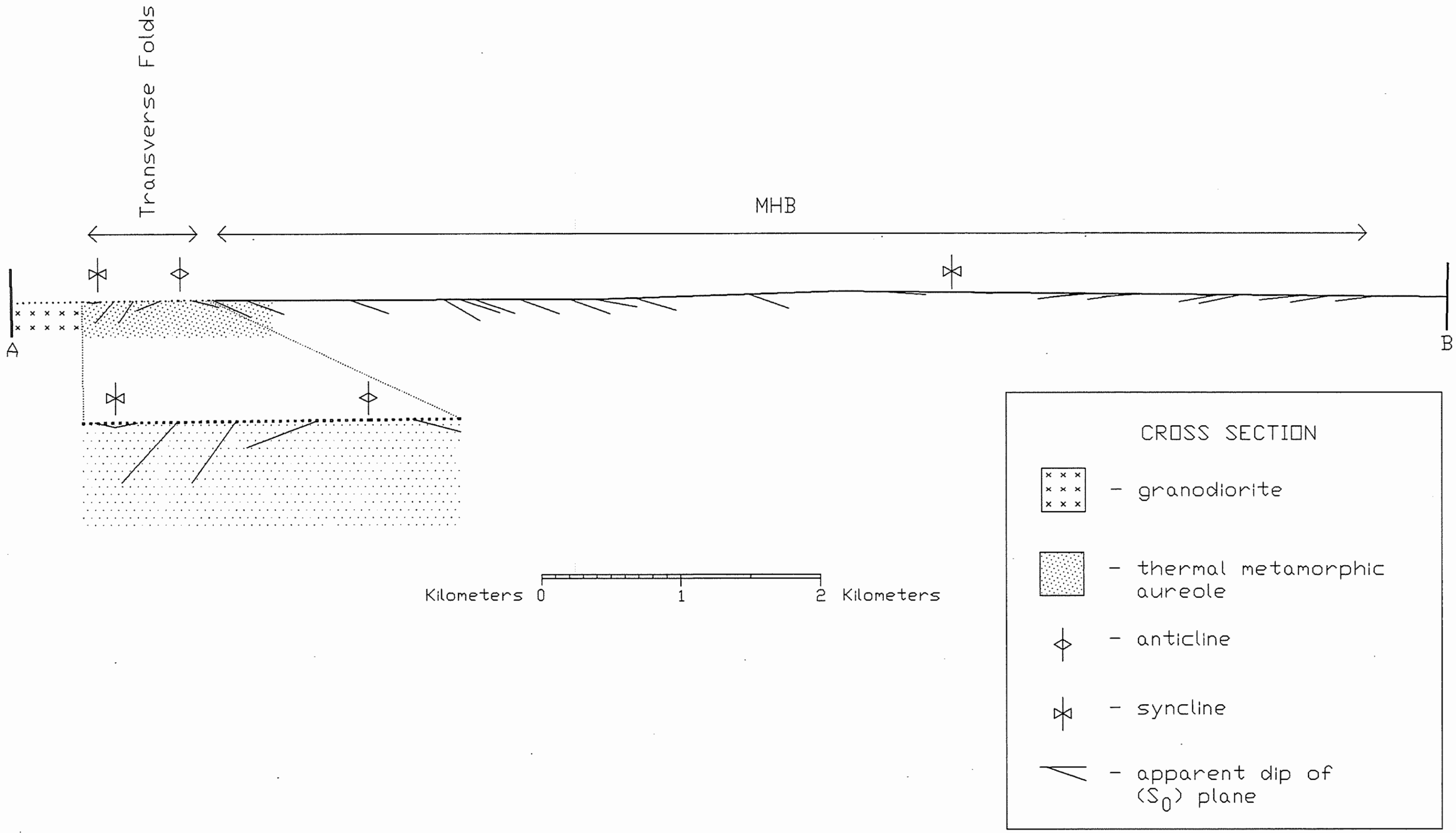

Figure 3.3 Cross-section of the Magazine Hill Basin along the Bedford Syncline from points A-B.

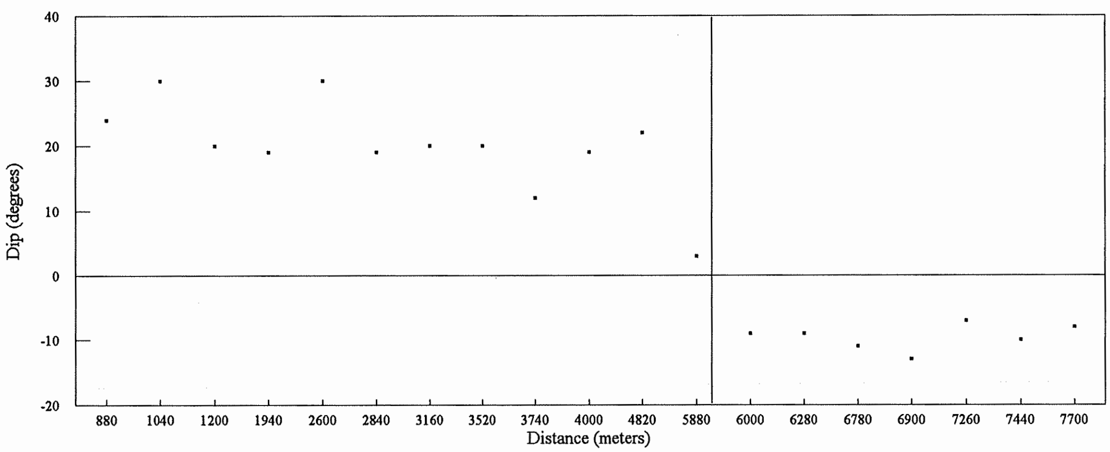

Figure 3.4 Plot of apparent dip against distance from the pluton contact along section line A-B. The vertical line represents the NW-SE hinge of the Magazine Hill Basin. Possitive values dip NE and negative values dip SW.

dip angle occurs away from the contact of the pluton within the MHB. A plot of apparent dip angle against distance from the contact (Fig. 3.4) shows this decreasing apparent dip.

Inspection of geological maps of the Meguma Terrane (Stevenson 1959; Taylor 1964, 1967, 1969; Henderson 1986; Corey 1987) does not reveal tranverse folding similar to that mentioned above. Folding within the Terrane generally follows the regional trend, and the plunge at the ends of periclinal folds is only slight. Thus, the presence of transverse folds parallel to the granite contact in the study area appears to be anomalous in the Meguma Terrane.

3.5 Summary

Bedding and cleavage are both present in the study area and larger structures include transverse folds and the MHB. The construction of cross-section along the Bedford Syncline illustrates the major structures and an increasing apparent dip of bedding toward the pluton contact. The increase in apparent dip toward the granite contact is taken to imply a cause and effect relationship between the granite emplacement and structure.

CHAPTER 4 INTERPRETATION AND IMPLICATIONS

4.1 Introduction

The increasing dip toward the granite contact, apparent in the cross-section, suggests an change in the geometry that may reflect an increase in strain toward the granite. This chapter investigates this theory of increasing strain to determine if the rocks reflect such a pattern.

4.2 Strain Along Section

Analysis of the cross-section reveals a number of features that appear to be related to the emplacement of the SMB. Normal (i.e., in the absence of pluton emplacement) regional folding within the Meguma produced periclinal folds with long cylindrical axial segments. Plunges of these folds are normally less than 10° (N. Culshaw 1995, pers. comm.). The cross-section however, contains apparent dip angles as high as 30° at the south-west end of the MHB, close to the contact. This steeper angle rules out the periclinal fold interpretation and supports the type 1 interference fold pattern interpreted to result from deformation related to pluton emplacement. The south-western end of the Waverley Anticline (Fig. 3.1) also appears to have been deformed in a similar fashion. It contains bedding that dips NE that may also be the result of deformation related to the emplacement of the SMB.

The simplest displacement pattern that explains the variation of apparent dip is a vertical, heterogeneous, simple shear imposed during vertical emplacement of the SMB.

To estimate the strain related to emplacement, I assume that the hinge of the Bedford Syncline was horizontal before a forceful vertical emplacement. Thus, the apparent dip of S_0 planes in the cross-section results from vertical heterogeneous simple shear (Fig. 4.1) and the apparent dip angle is the shear angle (ψ). Values of shear strain, calculated from shear angle, appear in Appendix B for each location along the cross-section. Figure 4.2 shows the apparent dip data recast as shear strain.

Because emplacement caused a vertical shear, the trace of the erosional surface on the cross-section is a line of net shortening (Fig. 4.3). Shortening is the amount of negative extension when extension (ε) is the present length minus the original length divided by the original length (l-l_o/ l_o). Values of shortening along the present erosion surface, at the different locations along the cross-section, are calculated and the method of calculation and results appear in Appendix B. Appendix C contains an explanation of the formulas and variables used to determine the amount of shortening at each location. Figure 4.4 shows the decreasing shortening along the erosion surface with distance from the pluton. Note that these values of shortening are low, and that the line of shortening was not originally parallel to the erosion surface.

Whereas shortening along the erosion surface was minor, extrapolation of S_0 traces along the section back to the pluton contact suggests roof-lifting by the pluton of approximately 1.5-1.8 km. This value is only approximate because the extrapolation in the region of the tranverse folds is invalid; however, the amount of vertical displacement is much larger than that of horizontal displacement along the section.

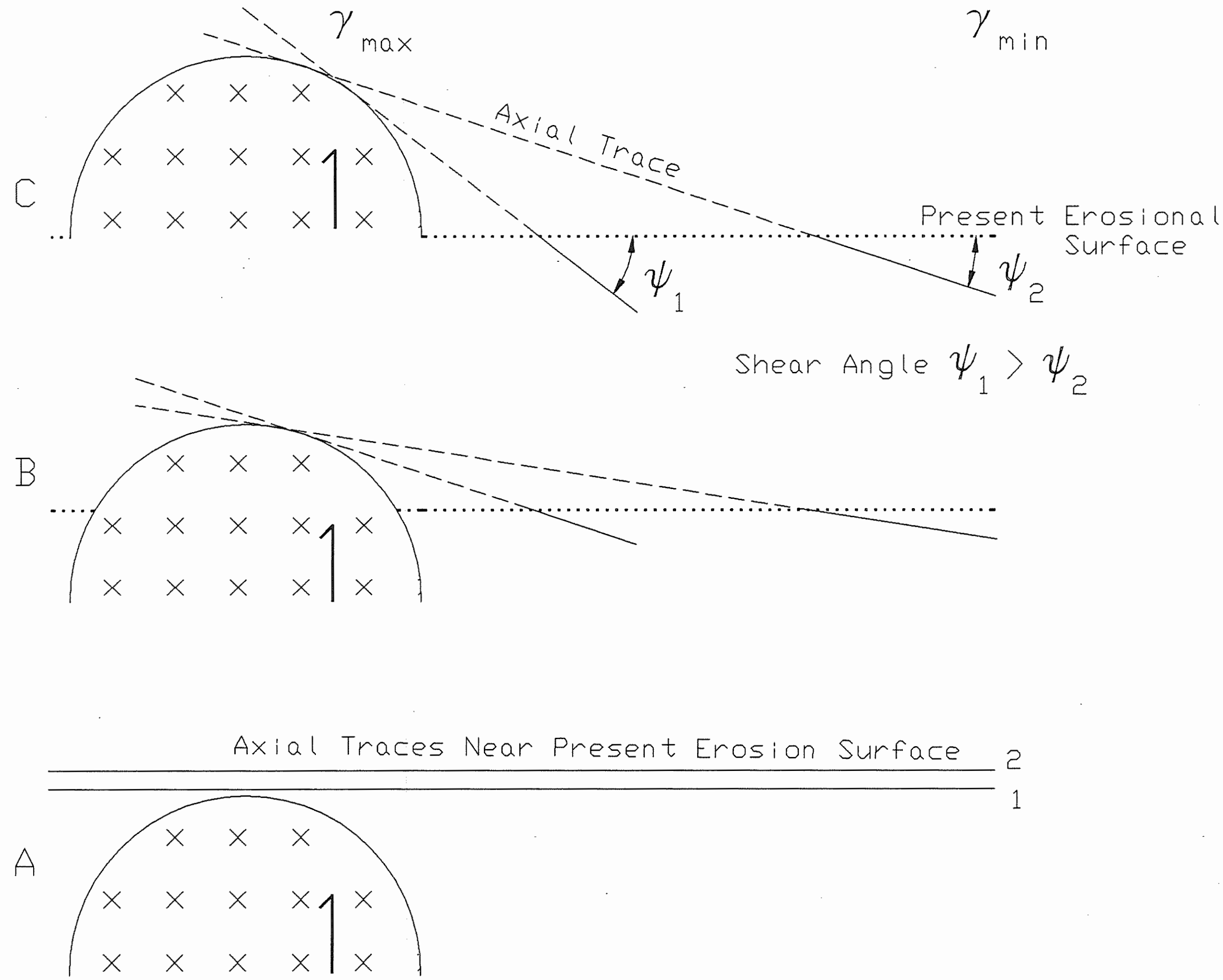

Figure 4.1 Possible emplacement model of the South Mountain Batholith showing the effects of vertical, heterogeneous simple shear. Pure shear is greatly exaggerated. A-B-C shows a progressive emplacement of a pluton.

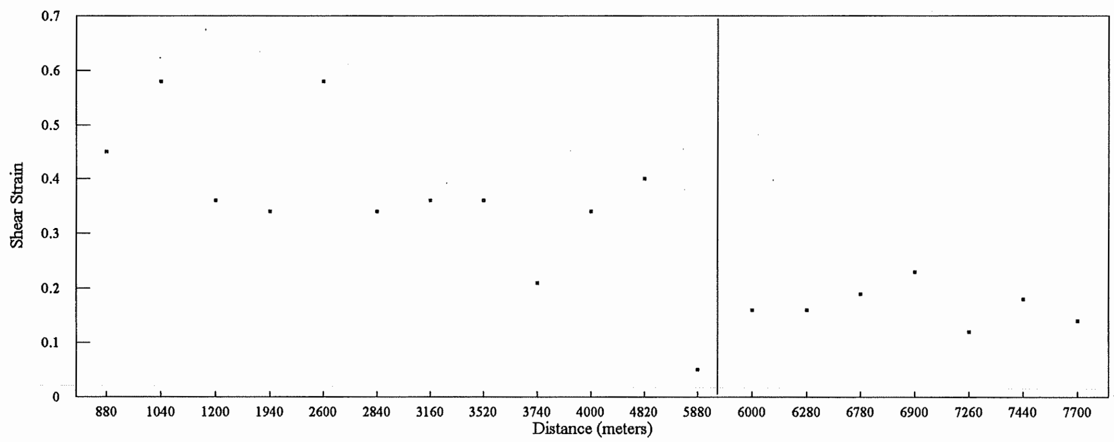

Figure 4.2 Plot of shear strain (dimensionless) against distance from the pluton contact. The vertical line represents the NW-SE hinge of the Magazine Hill Basin.

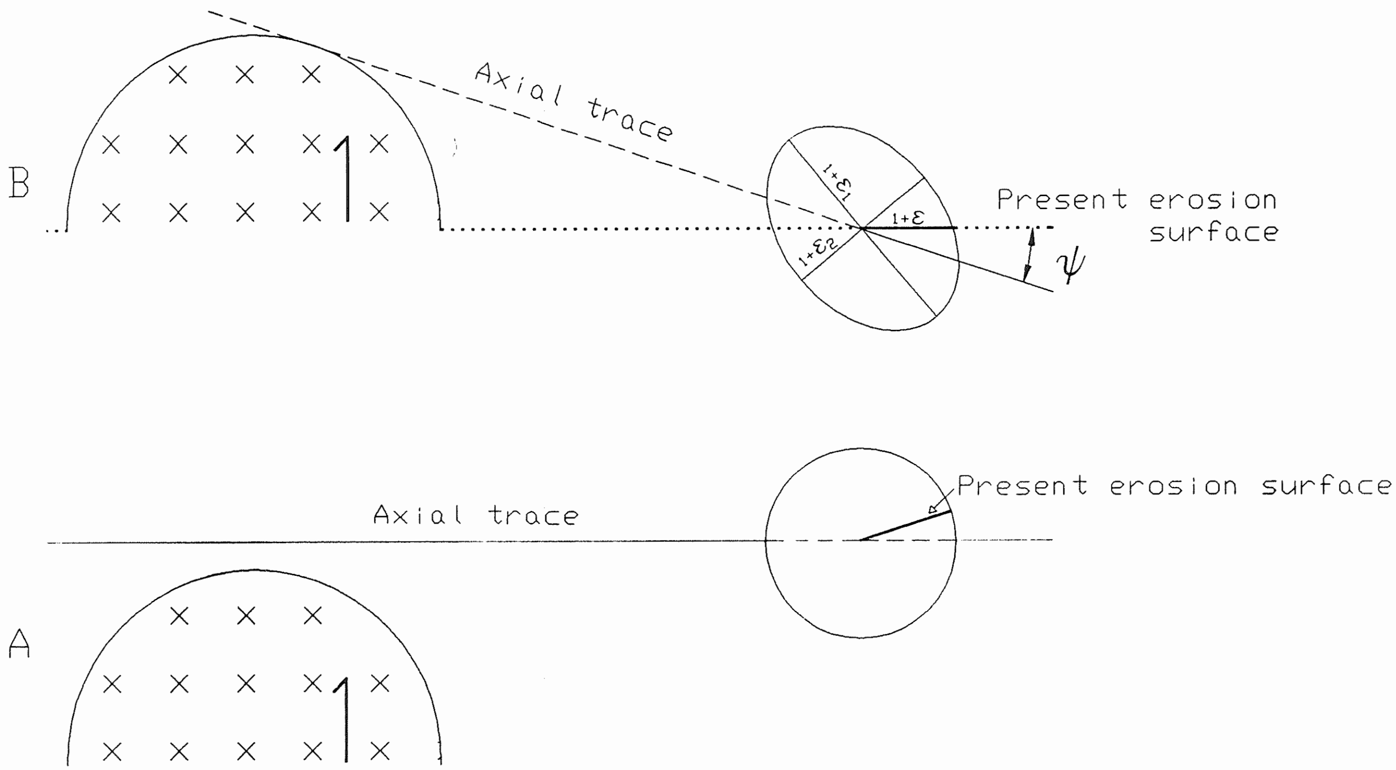

Figure 4.3 Strain model showing shortening in the horizontal plane assuming vertical forceful emplacement of the South Mountain Batholith. A-B represents different stages of emplacement.

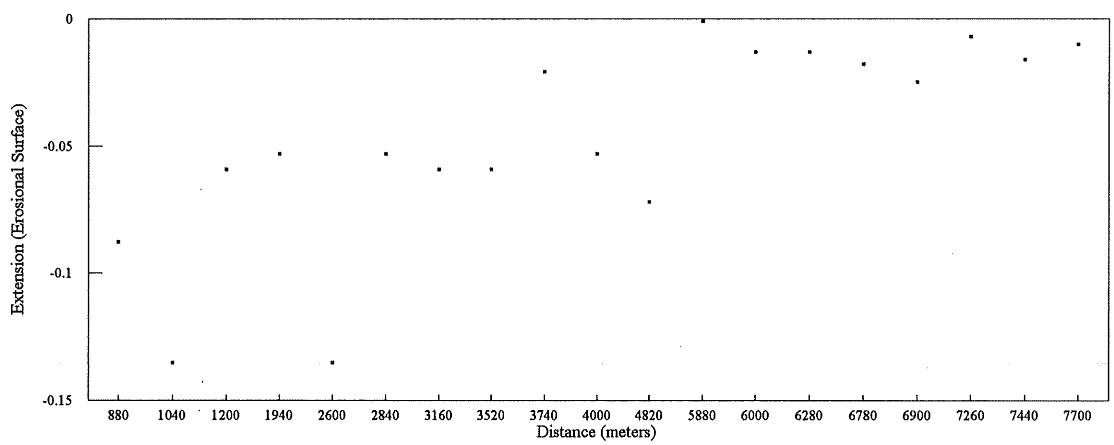

Figure 4.4 Plot of variation of negative extension, ε, (shortening) against distance from the pluton.

4.3 Strain Aureole

The cross-section (Fig. 3.3) contains two different types of structures. In addition, closest to the contact a third ductile regime may exist. This ductile regime is evident in outcrops near the Price Club area (just north of Bayers Lake, Fig. 1.3) where rock derived from the Halifax Slate contains an LS fabric with a vertical stretching lineation. This fabric resulted from the vertical shearing in the hottest part of the thermal aureole. Adjacent to the ductile regime, but still in the S_1-absent zone, is an area of relatively short wavelength transverse folding that is approximately 1-1.5 km wide. The Magazine Hill Basin defines a wide region of long wavelength folding. These different types of structures make up a three-part strain aureole adjacent to the contact of the granite.

What is the reason for the three-part division? Deformation within the strain aureole is most likely controlled by a number of different factors, probably with temperature the most important constraint. Deformation mechanisms are in large part dependent on temperature (Davis 1984), and temperature must have decreased away from the pluton during emplacement. Increasing the temperature of a rock typically decreases yield strength, enhances ductility, and lowers the ultimate strength of the rock (Davis 1984). Model plots of temperature against distance from a contact show an exponential decline from the contact (Jaeger 1968). The transition from ductile (LS fabric), through short wavelength (transverse folds), to long wavelength (MHB) folds, appears to mirror decreasing temperature and changing styles of deformation.

4.4 Cleavage

When rocks have undergone a sufficient amount of strain, a slaty cleavage typically forms perpendicular to the direction of maximum finite shortening (Heim 1919; Cloos 1947). This effect is apparent in both the Halifax and Goldenville Formations as a result of the strain that produced the regional folding (Fig. 3.1). A compressive strain in excess of 30 percent is needed to form slaty cleavage (Cloos 1947); however, the amount of negative extension (shortening) resulting from the SMB emplacement was low (maximum of ~15 percent), therefore cleavage or a NW-SE crenulation did not form.

4.5 Summary

Analysis of the cross-section reveals an increasing strain toward the pluton contact. This increasing strain may be the result of shear strain imposed by a vertical emplacement of the pluton consistent with the LS fabrics adjacent to the contact. The cross-section also reveals a 3-fold division of structures reflecting different temperature-controlled regimes that together comprise a strain aureole. Values of shortening measured along the section suggest a low maximum compressive strain that was not sufficient for cleavage formation.

CHAPTER 5 CONCLUSIONS

5.1 Conclusions

Previous workers considered that the SMB underwent passive emplacement. Indeed, most areas surrounding the pluton do not appear to contain any mechanical deformation related to the pluton; however, the results of this study appear to indicate a significant amount of vertical simple shear related to emplacement, compatible with considerable lifting of the pluton roof. The main results of this investigation include the recognition of increasing apparent dip toward the granite contact which is used to calculate shear strain and the amount of shortening of the present erosional surface. Although the findings of this investigation seem to show deformation related to emplacement, the study area was restricted and further work elsewhere is necessary to substantiate this hypothesis. The Waverley and Birch Cove Anticlines could be future areas of concentration that may help substantiate this claim. One of the products of this investigation is a database for use in future work.

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APPENDIX A

Table of Fieldlog data measured and compiled from the Bedford Basin Study Area
A copy of the Fieldlog database and the AutoCAD raw data map is on disks at the end of the appendix.

FRB- Data compiled from Faribault (1908).

Station	Easting	Northing	Bedding Strike	Bedding Dip
FRB-001	447517	4943823	99	75
FRB-002	446983	4944071	110	77
FRB-003	447391	4944352	90	75
FRB-004	447401	4944579	85	65
FRB-005	447352	4944860	78	62
FRB-006	446507	4945196	143	25
FRB-007	446498	4945531	117	22
FRB-008	446217	4945719	145	45
FRB-009	446115	4945866	119	55
FRB-010	446105	4945987	121	35
FRB-011	446501	4946803	75	42
FRB-012	446875	4946941	71	50
FRB-013	447198	4947046	71	60
FRB-014	446548	4946962	211	30
FRB-015	446723	4947104	211	40
FRB-016	446903	4947201	212	40
FRB-017	446507	4947207	228	32
FRB-018	446397	4947365	229	30
FRB-019	447054	4947585	230	40
FRB-020	446860	4947704	232	47
FRB-021	445661	4947353	176	45
FRB-022	445175	4947920	169	30
FRB-023	445331	4947906	175	30
FRB-024	445410	4947957	176	35
FRB-025	445544	4947957	154	35
FRB-026	446106	4948018	240	49
FRB-027	444992	4948231	129	40
FRB-028	445233	4948325	137	30
FRB-029	445689	4948482	277	10
FRB-030	444771	4948339	135	30
FRB-031	444974	4948414	132	40
FRB-032	445264	4948498	137	25
FRB-033	445569	4948682	284	20
FRB-034	445337	4948823	284	20
FRB-035	444919	4949168	294	15
FRB-036	444613	4949339	310	20
FRB-037	444204	4948816	127	55
FRB-038	447474	4948570	233	45
FRB-039	447421	4948996	245	35
FRB-040	447355	4949263	245	27
FRB-041	447368	4949638	247	20

Appendix A Table of field data

Station	Easting	Northing	Bedding Strike	Bedding Dip
FRB-042	447220	4949907	258	25
FRB-043	447192	4950595	270	20
FRB-044	446609	4950822	292	20
FRB-045	446820	4951204	340	15
FRB-046	446850	4951376	352	17
FRB-047	446888	4951630	18	20
FRB-048	447011	4951885	23	20
FRB-049	446607	4951569	344	17
FRB-050	446316	4951252	312	10
FRB-051	446316	4950833	294	10
FRB-052	445664	4950392	325	30
FRB-053	445601	4950781	340	20
FRB-054	445138	4951896	360	15
FRB-055	444901	4951880	324	18
FRB-056	444280	4951633	329	15
FRB-057	444113	4951437	330	20
FRB-058	444010	4951106	335	20
FRB-059	443725	4951365	324	20
FRB-060	443551	4951529	294	20
FRB-061	443524	4951358	300	15
FRB-062	443900	4950743	330	20
FRB-063	443534	4950849	312	20
FRB-064	443706	4950640	330	22
FRB-065	443863	4950380	330	23
FRB-066	444036	4950076	330	28
FRB-067	444382	4949607	330	25
FRB-068	444114	4949685	330	26
FRB-069	443879	4949703	329	25
FRB-070	443689	4949781	351	15
FRB-071	443477	4949786	121	20
FRB-072	443491	4950227	339	20
FRB-073	443137	4950342	338	10
FRB-074	443012	4950247	103	22
FRB-075	442751	4950423	113	10
FRB-076	442782	4950887	300	25
FRB-077	442831	4951030	273	22
FRB-078	442853	4951149	288	22
FRB-079	442198	4951263	276	29
FRB-080	441902	4951549	233	40
FRB-081	441979	4951870	239	50
FRB-082	441643	4951741	244	50
FRB-083	441658	4951211	191	20
FRB-084	440569	4950950	277	21
FRB-085	441004	4950985	263	15
FRB-086	441110	4950762	184	40
FRB-087	441738	4950457	189	20
FRB-088	441746	4950084	299	15
FRB-089	442214	4950544	139	15
FRB-090	442232	4949963	147	15

Station	Easting	Northing	Bedding Strike	Bedding Dip
FRB-091	442466	4949842	180	18
FRB-092	442310	4949608	294	3
FRB-093	442636	4949288	295	11
FRB-094	443198	4949339	139	12
FRB-095	443076	4949209	299	12
FRB-096	443581	4949115	165	55
FRB-097	447925	4944596	90	65
FRB-098	447880	4944377	83	65
FRB-099	448294	4944347	86	70
FRB-100	448859	4944603	66	72
FRB-101	448969	4945196	71	75
FRB-102	449280	4944922	68	72
FRB-103	449347	4945451	72	75
FRB-104	449756	4945801	71	80
FRB-105	449401	4946207	70	70
FRB-106	448453	4946054	69	71
FRB-107	448812	4947063	77	74
FRB-108	448488	4947437	80	80
FRB-109	447834	4947337	80	55
FRB-110	447868	4947562	88	32
FRB-111	447882	4948555	233	40
FRB-112	448399	4950915	46	21
FRB-113	448228	4951057	257	30
FRB-114	448045	4951185	262	26
FRB-115	447777	4951362	262	20
FRB-116	447886	4951727	260	20
FRB-117	449843	4951867	227	30
FRB-118	447301	4952765	39	26
FRB-119	447319	4953154	44	22
FRB-120	449151	4952446	238	20
FRB-121	448749	4952666	233	20
FRB-122	450215	4952149	226	35
FRB-123	449537	4953102	225	20
FRB-124	450259	4953718	228	20
FRB-125	450752	4954033	223	29
FRB-126	450977	4954298	217	22
FRB-127	451648	4952249	242	10
FRB-128	451401	4952409	239	30
FRB-129	451292	4952642	229	25
FRB-130	449433	4953465	80	20
FRB-131	449750	4953836	80	25
FRB-132	450068	4953856	80	20
FRB-133	450215	4954213	68	24
FRB-134	450629	4954498	73	25
FRB-135	448904	4943201	103	58
FRB-136	449583	4943301	102	45
FRB-137	450117	4943299	93	45
FRB-138	449938	4943528	71	40
FRB-139	450674	4943483	77	67

Appendix A Table of field data

Station	Easting	Northing	Bedding Strike	Bedding Dip
FRB-140	451243	4943452	90	20
FRB-141	451239	4943228	234	10
FRB-142	451151	4942821	212	17
FRB-143	449125	4943731	83	70
FRB-144	449831	4943832	72	35
FRB-145	449150	4944315	74	80
FRB-146	449138	4944311	58	62
FRB-147	450872	4943904	76	25
FRB-148	450932	4945870	70	65
FRB-149	451447	4945571	67	45
FRB-150	451890	4945879	70	65
FRB-151	450992	4946607	79	58
FRB-152	451729	4946459	67	65
FRB-153	452119	4946268	65	60
FRB-154	452367	4945899	70	65
FRB-155	452501	4945707	72	65
FRB-156	452843	4945321	67	63
FRB-157	453487	4945448	70	55
FRB-158	453014	4945823	68	68
FRB-159	453764	4945759	66	62
FRB-160	454205	4946312	68	70
FRB-161	453767	4946778	70	60
FRB-162	453474	4947119	72	65
FRB-163	451068	4947859	64	72
FRB-164	450913	4948445	60	65
FRB-165	451884	4948884	60	75
FRB-166	452810	4948923	70	64
FRB-167	453456	4948768	67	42
FRB-168	453543	4948513	65	54
FRB-169	453819	4948499	65	41
FRB-170	453879	4948858	64	33
FRB-171	454030	4949150	65	71
FRB-172	453480	4949442	67	33
FRB-173	451958	4950444	343	15
FRB-174	452547	4950412	320	15
FRB-175	453610	4951093	56	25
FRB-176	454272	4951079	40	20
FRB-177	454363	4950685	40	35
FRB-178	454337	4950557	44	35
FRB-179	454569	4950932	56	35
FRB-180	454846	4950660	45	42
FRB-181	455191	4950462	47	48
FRB-182	455277	4950355	46	40
FRB-183	455316	4951155	232	68
FRB-184	455598	4951273	232	68
FRB-185	455102	4951473	24	25
FRB-186	454720	4951196	72	28
FRB-187	454803	4951512	18	23
FRB-188	454522	4951469	7	15

NBN: data compiled from author

Station	Easting	Northing	Bedding Strike	Bedding Dip	Cleavage Strike	Cleavage Dip
NBN-001	443255	4951593	277	25	258	85
			325	30		
NBN-002	444521	4952232	334	13	60	78
NBN-003	443750	4950407	301	19		
NBN-004	445185	4952043	356	15	60	70
NBN-005	444649	4950902	357	28	62	80
NBN-006	443562	4951501	319	22	70	72
NBN-007	443065	4951264	306	20	260	65
			74	18		
NBN-008	448844	4952522	243	14	58	74
NBN-009	449244	4952106	241	17	35	68
NBN-010	448697	4953943	58	36	50	68
NBN-011	447648	4955087	58	36		
			50	50		
NBN-012	447506	4953451	52	28	54	73
NBN-013	449083	4953261	89	9	255	75
NBN-014	446267	4952939	24	11	52	60
NBN-015	446133	4952871	56	18		
			51	4		
NBN-016	448387	4951700	246	10		
NBN-017	448045	4951989	233	13	55	65
NBN-018	446815	4952324	346	10	52	86
NBN-019	446260	4951289	300	7	55	72
NBN-020	446003	4951169	35	25		
			35	7		
NBN-021	443116	4952166	261	26	250	78
NBN-022	444339	4949547	294	29	55	75
NBN-023	445811	4950524	299	18	55	70
NBN-024	447196	4950093	262	40	59	73
NBN-025	450464	4954930	60	68		
NBN-026	449331	4955078	70	35	56	65
NBN-027	449634	4954524	55	88		
NBN-028	449291	4953636	239	17	235	81
NBN-029	443391	4950856	319	22	55	73
NBN-030	444883	4949011	280	26		
NBN-031	445593	4948341	274	9		
NBN-032	446764	4947555	258	73	234	81
NBN-033	447911	4947194	70	48	65	79
NBN-034	447637	4948779	243	19	225	74
NBN-035	449512	4953406	70	46		
NBN-036	450235	4951939	242	17	50	75
NBN-037	448978	4953215	79	16	53	64

APPENDIX B

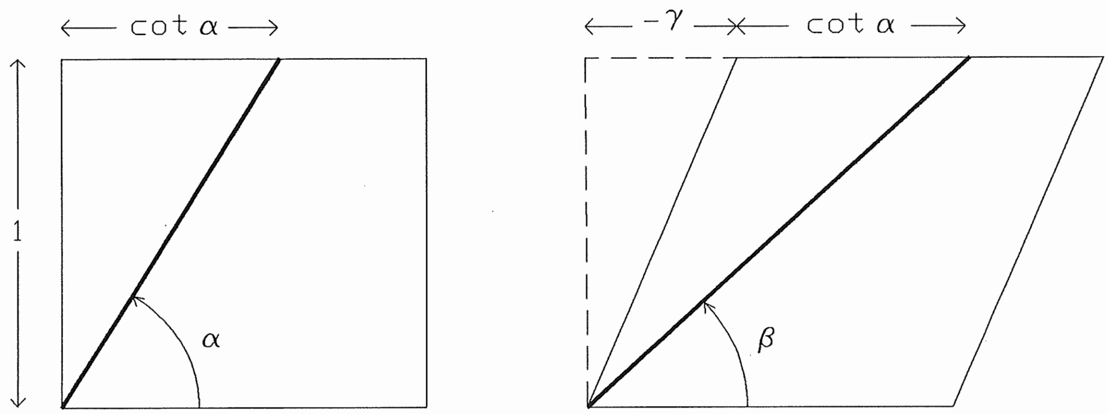
Measured and calculated data from cross-section A-B (Fig. 3.2)

Distance: distance of the measurement from the granite contact
Dip: apparent dip of bedding on the section plane A-B
Shear Strn. shear strain derived assuming apparent dip is shear angle i.e. tan(apparent dip) = shear strain
Ext.(E.S.) shortening of line lying in erosional surface assuming derived shear strain

Distance (m)	Dip	Shear Strn.	Ext. (E.S)
880	24	0.45	-0.088
1040	30	0.58	-0.135
1200	20	0.36	-0.059
1940	19	0.34	-0.053
2600	30	0.58	-0.135
2840	19	0.34	-0.053
3160	20	0.36	-0.059
3520	20	0.36	-0.059
3740	12	0.21	-0.021
4000	19	0.34	-0.053
4820	22	0.4	-0.072
5880	3	0.05	-0.001
6000	-9	0.16	-0.013
6280	-9	0.16	-0.013
6780	-11	0.19	-0.018
6900	-13	0.23	-0.025
7260	-7	0.12	-0.007
7440	-10	0.18	-0.016
7700	-8	0.14	-0.01

APPENDIX C

Calculation of extension of a line in a zone of homogeneous simple shear when shear strain is known.



β.......angle between line and shear plane (90-dip), after shearing (known)
γ........shear strain (known)
α.......angle line made with shear plane before shearing (unknown)
ε........extension of the line (unknown)

Extension of a line of known orientation before shear strain varies with shear strain as:

$\varepsilon=[1-2\gamma\cos(\alpha)\sin(\alpha)+\gamma^2\sin^2(\alpha)]^{1/2}-1$

α is found using:

$\cot(\beta)=\cot(\alpha)-\gamma$

(Ramsay and Huber 1983)