PETROLOGY OF THE SOUTH MOUNTAIN BATHOLITH, WESTERN NOVA SCOTIA

by

Colin B. McKenzie

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DALHOUSIE UNIVERSITY

Faculty of Graduate Studies

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Chairman, Thesis Committee

Committee Member

Committee Member

Committee Member

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Date

DALHOUSIE UNIVERSITY

Date______________

Author COLIN B. McKENZIE

Title PETROLOGY of the SOUTH MOUNTAIN BATHOLITH, WESTERN NOVA SCOTIA.

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ABSTRACT

Approximately one-third of western Nova Scotia is covered by the Middle to Upper Devonian granitic rocks of the South Mountain batholith. The pluton consists largely of a sea of granodiorite enclosing four large adamellitic bodies as well as numerous smaller intrusives and alaskitic dykes. The batholith has invaded regionally metamorphosed Cambrian to Lower Devonian sequences late in the Acadian orogenic cycle. On a large scale the batholith parallels the regional structural trends, however locally it cuts across the Acadian fold structures.

Chemical analyses show that the various rock types of the batholith can all be representatives of a single comagmatic suite, most likely related to one another by fractional crystallization. Comparison of the bulk compositions of the granitic rocks with experimentally determined phase relations in the residua system, in conjuction with such considerations as stratigraphy and structure, all point to lower epizone-upper mesozone emplacement of the batholith. In addition, the occurrence of primary andalusite in late-stage rocks suggests that the final P,T conditions of crystallization were 3.3-3.9 kb and 650-680^{o}C.

In plate tectonic terms, the Devonian granites of Nova Scotia are at least spatially and perhaps temporally related to a subduction zone which gave rise to the New Canaan volcanics in Silurian times. The rather silicic average composition of the batholith and intermediate Sr87/86 ratios suggest that the parent magma was created from a combination of mantle and crustal rocks.

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CHAPTER 1: INTRODUCTION AND GEOLOGICAL SETTING

I Introduction

Approximately one-third of Nova Scotia west of Halifax is underlain by a large, continuous body of granitic rock. The body consists primarily of granodioritic and adamellitic lithologies. A series of dyke rocks and small intrusive bodies are volumetrically minor. The body has invaded pre-folded and metamorphosed Cambrian to Lower Devonian sequences late in the Acadian orogenic cycle. It is arcuate in shape and on a regional scale parallels the Acadian structural trends. Locally, however, it abruptly truncates individual fold structures.

The pluton (which henceforth will be referred to as the South Mountain batholith) outcrops over some 2500 square miles (6400 $km.^2$) of mid-western Nova Scotia. The thesis area is restricted to the central 1500 square miles (4000 $km.^2$) of the batholith. Nova Scotia highways 8 (Annapolis Royal-Liverpool) and 14 (Windsor-Chester) form the arbitrary western and eastern limits of the area respectively, while Paleozoic metasediments form the north and south boundaries.

II Regional Geological and Tectonic Setting

The regional Appalachian geology of the Meguma platform (i.e. Nova Scotia southwest of the Cobequid-Chedabucto fault system) is rather anomalous in terms of the regional picture. For example, the Cambro-Ordovician Meguma Group shows no evidence of involvement in the mid-Ordovician

Taconic orogeny which strongly deformed other parts of the northern Appalachians (Neale _et al._, 1961; Poole, 1967). Moreover, Schenk (1970) has shown by provenance studies that the source of the Meguma rocks was a land mass to the southwest of present-day Nova Scotia. A further example of the alien nature of this area is the fact that its Devonian sequences have Rhenish- rather than Appalachian-type fossil assemblages (Boucot, 1960).

Schenk (1971) has suggested that this uniqueness stems from the possibility that western Nova Scotia was, until the Devonian continental collision (Wilson, 1966), a part of Africa. Schenk believes that the Mesozoic re-opening of the Atlantic left this "African erratic" on the North American side of the new spreading centre. Subsequent strike slip movements along the Cobequid-Chedabucto fault brought the Meguma platform to its present position. Indeed, Schenk has shown that southwestern Nova Scotia will lie adjacent to part of North Africa when a Bullard-type reconstruction of Pangea is coupled with a palinspastic restoration of the Cobequid-Chedabucto and South Atlas (Morocco) faults. He also points to the Ordovician/Silurian volcanics along the northwest side of the region as evidence that it once lay to the east of a consuming plate margin. The theory is still tenuous, but it does offer some help in accounting for the exotic nature of western Nova Scotia Appalachian geology.

III Geological Setting of Western Nova Scotia

Western Nova Scotia, for the purposes of this and following discussions, is defined as that portion of the province lying west of a line running northwest from Halifax to Windsor. 50% of this region is underlain by the Cambro-Ordovician Meguma Group which is comprised of the Goldenville Formation and the younger Halifax Formation. The Goldenville Formation is a sequence of continental rise turbidite quartzites and interbedded shales (Schenk, 1971). The base of the formation is unknown, but the minimum stratigraphic thickness is 5.5 km (Taylor, 1969).

The Halifax Formation consists of 3.7 km. of slates, black shales and thin, lensoid sands (Taylor, 1969) which are believed to have been deposited in an abyssal plain environment (Schenk, 1971). The boundary between the two formations is somewhat arbitrarily defined by a sand/shale ratio of 1.

Outcropping along the north side of the area in tightly folded synclines are a series of Ordovician/Silurian and Devonian clastics and volcanics. The Ordovician/Silurian sequence is made up of the White Rock, Kentville and New Canaan Formations (oldest to youngest respectively). The former outcrops intermittently along the entire length of western Nova Scotia whereas the Kentville Formation extends as far west as Digby and the New Canaan Formation is restricted to a small area south of Kentville. The Lower Devonian Torbrook Formation is the youngest pre-granitic sequence in the region.

A wide variety of siliciclastics in addition to volcanics and minor volcaniclastics are present in the White Rock Formation. According to Taylor (1967), the volcanics are primarily andesites with some associated basalt and rhyolite. They attain a maximum thickness of slightly over 3 km. in the Yarmouth area. The petrologic affinities are not yet well established but recent analyses suggest they may comprise an alkaline rather than a calc-alkaline suite (P. Sarkar, personal comm.).

The Kentville Formation is primarily a black shale sequence which contains Ludlovian age graptolites and corals (Smitheringale, 1960). Both the Kentville and White Rock Formations thicken from east to west; the former attaining a maximum stratigraphic thickness of 5 km., the latter reaching approximately 1 km. (Smitheringale, 1973). The New Canaan Formation is composed of siliciclastics, volcanics (andesitic), volcaniclastics and minor carbonates. It has a minimum thickness of .3 km. (Crosby, 1962).

The ages of the New Canaan and Kentville Formations are well-defined on fossil evidence as Niagaran and Ludlovian respectively (Taylor, 1969). The White Rock is less well known and, as Taylor (1969) suggests, it may span the time interval between the top of the Halifax Formation (Lower Ordovician) and the base of the Kentville series.

The Torbrook Formation is exposed only in the Nictaux-Torbrook and Bear River areas. It is mostly siliciclastics with minor carbonates and tuff layers (Smitheringale, 1960, 1973; Taylor, 1969, Jensen, personal comm.). The Torbrook

Formation is very fossiliferous and its paleontologic age is well-defined as Lower Devonian (Gedinnian to Emsian). This formation also thickens from east to west, ranging from 1.5 km. in the Nictaux-Torbrook vicinity to 3 km. near Bear River (Taylor, 1969).

Tectonic activity during the mid-Devonian Acadian orogeny has compressed the above Paleozoic sediments and volcanics into tight, nearly isoclinal folds. The structures are gently plunging and generally trend NE-SW. There is, however, a rather abrupt change in structural trend about a hinge line joining Digby and Shelburne. West of this line the regional structure swings to become approximately N-S. Faulting in western Nova Scotia is minor (Taylor, 1969; Smitheringale, 1973).

The regional metamorphic grade is greenschist facies (Taylor and Schiller, 1966). Higher grades do occur in the southwest corner of the province; however, these are outside the thesis area. Taylor (1969) has recognized at least three metamorphic subfacies in the pelitic and psammitic Paleozoic rocks. Overprinted on the regional metamorphism are the thermal effects of granitic intrusion. Contact metamorphism is generally of the hornblende-hornfels facies and assemblages consist of quartz-biotite-muscovite-plagioclase-cordierite-andalusite with small amounts of garnet, staurolite and sillimanite (Taylor and Schiller, 1966). The aureole varies from .5 to 2.5 km. in width.

IV <u>Geology of the Granitic Rocks in Western Nova Scotia</u>

The South Mountain batholith was emplaced after the folding and metamorphic events of the Acadian orogeny. It is a granodiorite/adamellite complex consisting of several petrologically distinct phases. Biotite granodiorite is the dominant lithology present, whereas a number of later 2-mica adamellites, dyke rocks and minor intrusive bodies constitute the remainder of the pluton. The areal distribution of the various phases is shown in Fig. 1.1. Petrography and field relations are described in detail in Chapters 3, 4 and 5.

Structurally, the batholith is generally concordant with Acadian fold trends on a regional scale, but often abruptly truncates fold structures on a local scale. At the eastern end of the batholith there is a large metasedimentary inlier (roof pendant) which has retained its structural conformity with the country rocks. Mineral lineations and other internal structural elements are only occasionally present and do not seem to be related to the regional pattern. On the strength of this and other evidence, Buddington (1959) defined the South Mountain batholith as an upper mesozonal to epizonal pluton.

The batholith has been dated both by paleontological and radiometric means. Along its northern perimeter, the granitic rocks intrude fossiliferous Lower Devonian (Emsian) sediments while Lower Carboniferous rocks unconformably overlie the intrusives in both the Windsor and St. Margaret's Bay areas. Thus, the paleontological evidence indicates a Middle to Upper Devonian age. The several groups of K-Ar

Figure 1.1: Geologic map of the South Mountain batholith.

Explanation:

Carboniferous and Triassic

Devonian granitic rocks

- Minor intrusive bodies
  1. Greywood leucoadamellite
  2. Morse Road adamellite
  3. Inglisville alaskite
  4. Murphy Lake alaskite
- New Ross-Vaughn complex
- Lake George adamellite
- Springfield Lake adamellite
- West Dalhousie adamellite
- Biotite granodiorite

Siluro-Devonian and Cambro-Ordovician

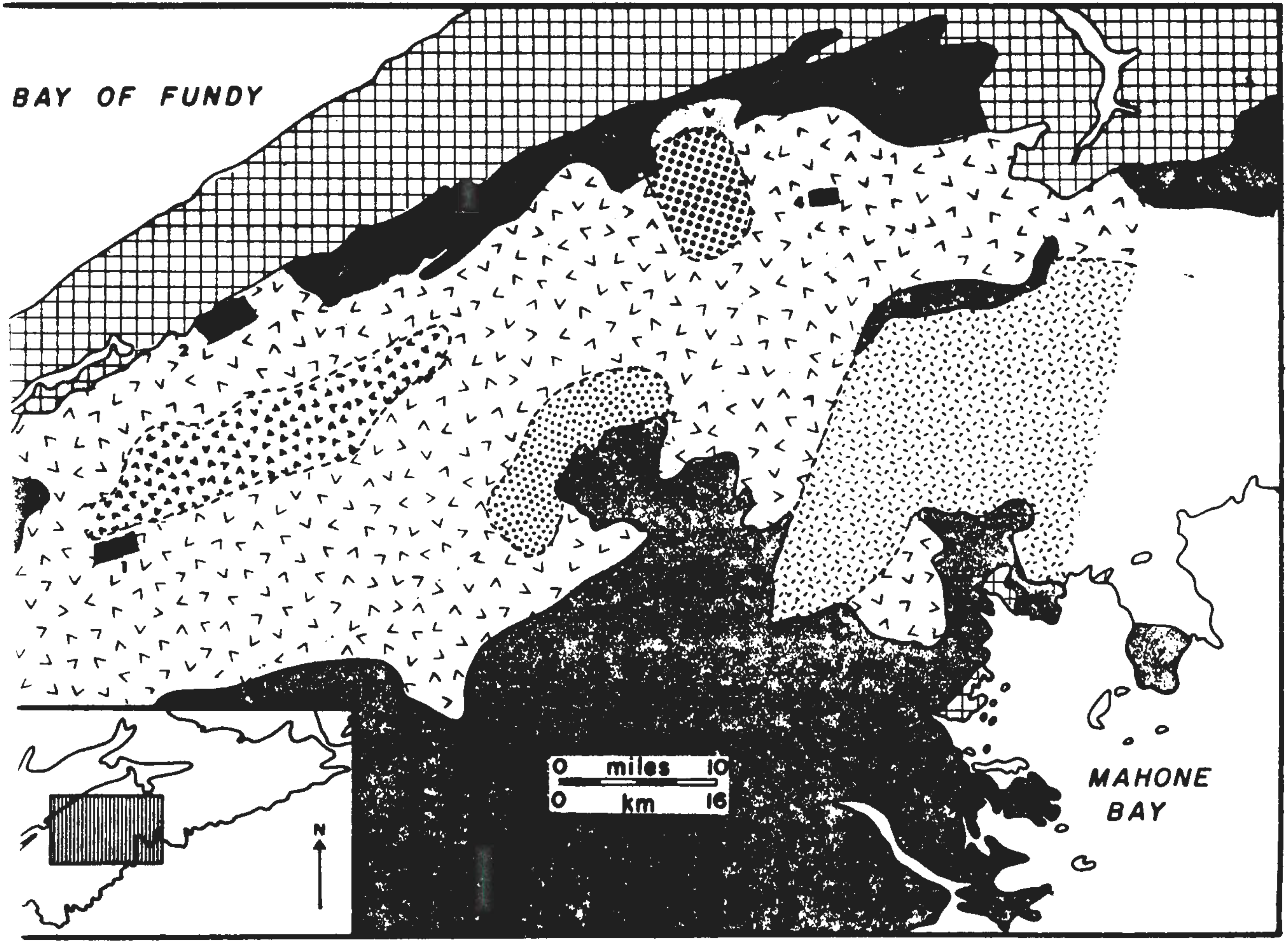


FIG. 1.1

and Rb-Sr dates that have been done for the batholith (Fairbairn et al., 1969, 1964; Cormier and Smith, 1973; Reynolds et al., 1973), give ages ranging from 417 ± 38 m.y. to 350 ± 7 m.y. The average age is about 370 m.y. and this generally agrees with the paleontological data.

Mineral occurrences of economic interest in the batholith are restricted to an area of low gravity and high heat flow centred about New Ross, Lunen. Co. The mineralizations are associated with late-stage pegmatites and greisen zones and are of the tin-tungsten-molybdenum variety. Manganese has also been prospected in this area, but it is associated with a fault zone rather than late magmatic processes. All the showings are small and presently have no economic viability (Taylor, 1969).

V Purpose of Research

At the time this study was undertaken, the granitic rocks of western Nova Scotia had been investigated only in a cursory manner. Several workers (Wright, 1931; Faribault, Armstrong and Wilson, 1939; Smitheringale, 1960, 1973; Taylor, 1969) mapped restricted areas of the intrusives, but no regional synthesis or modern petrologic work had been attempted. Recently, Smith (1973) has completed a geochemical and petrologic assessment of the eastern end of the South Mountain batholith, but his study area was too restricted to permit a comprehensive view of the pluton.

This project was begun in 1972 as reconnaissance of some 4000 km^2 of the central portion of the South Mountain batholith. The thesis area is bounded in the east by Route 14, in the west by Route 8 and to the north and south by pre-granitic metasediments (Map 1). Within the thesis area, only granitic rocks in the Nictaux-Torbrook and New Ross vicinities had been mapped while geochemical and petrologic data were virtually non-existent. Thus the aims of this study were:

1. to identify and map the different granitic phases occurring in the thesis area,
2. to study the petrography, geochemistry and age relations of the various phases,
3. to place the different granitic types in a petrologic framework that would permit interpretation of their origins, crystallization histories and inter-relations,
4. to understand the development of the batholith as a whole,
5. to lay the necessary groundwork for future petrological, geochemical and economic investigations.

VI Summary

The South Mountain batholith and the smaller granitic plutons intruding the Meguma platform represent the final stages of Devonian continental collision. With the cessation of Silurian volcanism and the completion of folding, plutonic activity took over and a series of granodiorites, adamellites, dyke rocks and minor intrusive bodies were emplaced at high crustal levels. Intrusive activity may have continued through much of the Middle and Upper Devonian with the last manifestations of the plutonic event being

CHAPTER 2: STRUCTURE

I Introduction

The overall concordancy of the South Mountain batholith with regional structural trends indicates that the emplacement of the pluton was largely controlled by the pre-existing Acadian structural framework. However, the way in which the granitic rocks often cross-cut individual anticlinal and synclinal structures, the sharp intrusive nature of the batholith/country rock contacts and the lack of any pronounced internal structures indicate that granitic invasion was post-tectonic and relatively passive. Moreover, as shear zones and faults are rarely observed within the batholith, it appears that the pluton has not undergone any major deformation since its intrusion.

Gravity and magnetic data (Garland, 1953) add a third dimension to the pluton. The batholith appears to be funnel-shaped with a cylinder of low density granitic rock 55 km. in diameter and 17 km. deep centred about New Ross, Lunenburg Co.

II Granite/Metasediment Contacts

Both in areas where the intrusive/metasediment contact approximately parallels regional structural trends and also where fold structures are abruptly cut by the granitic rocks, the igneous invasion has had little deformational effect on the enveloping country rocks. Contacts (in the few places they were observed) are sharp, migmatite zones are rare and not extensive when they do occur, and there are no local disruptions of structural trends. The principal manifestations of granitic intrusion are thermal metamorphism and alignment within the contact aureole of elliptical cordierite porphyroblasts and micas subparallel to the contact. Apophyses of aplite, pegmatite and quartz may also cross-cut the contact zone.

The above general characteristics, however, must be qualified by observations on the contact zone north of Chester Basin, Lunenburg Co. In this area there is evidence that local deformation has occurred under the influence of granitic emplacement. Several small sand lenses have been isoclinally folded while cordierite porphyroblasts have been stretched and aligned parallel to the contact. In addition, the metasediments have undergone incipient melting, as demonstrated by the presence of small, discordant aplitic lenses. The deformation of this contact zone may be due to the local geometry of the country rocks. Fig. 1.1 shows that the metasediments in this area are surrounded on three sides by granitic rocks. This configuration would tend to impede heat dissipation from the area and thus sufficient temperatures could be attained to initiate plastic deformation and partial melting.

The granitic rocks are rarely affected by their proximity to the contact zone. Biotite granodiorite, the granitic type most commonly found in contact with the metasedimentary envelope, sometimes shows a slight reduction in grain size and/or an increase in alkali feldspar content and/or pinkish colouration at the contact, but these features do not persist for any appreciable distance into the batholith. Gneissic textures, chill zones and large numbers of country rock enclaves are, for the most part, absent.

Other granitic types have not been observed in direct contact with the metasediments. However, adamellite outcrops within a few hundred meters of inferred contacts appear to be unaffected by the contiguity of the contact zone. This suggests either that the contact features are observable only within several meters of the intrusive/metasedimentary boundary or, that like the granodiorites, the adamellites underwent very little modification during their emplacement.

Contacts between the granitic lithologies and the three metasedimentary inliers enclosed in the batholith are complex. Two small inliers (one south of Annapolis Royal, the second south of Greenwood, Kings Co.—Map 1) are in contact with a peculiar contact facies granodiorite. The rock is biotite-rich, contains plagioclase phenocrysts 2 cm. long and has numerous xenoliths. It appears that in order to form this unusual contact lithology, granodioritic magma may have undergone extensive mixing with partially melted sediment.

The large Meguma inlier or roof pendant in the eastern end of the thesis area (Fig. 1.1) separates biotite granodiorite in the north from a series of 2-mica adamellites to the south. The granodiorites show some shearing and alteration near the inlier, but generally have no distinctive contact features. South of the inlier, however, there are at least three 2-mica granitic types adjoining the metasediments. These rocks differ texturally, but all have pinkish or reddish colourations and are rather extensively altered. The inlier itself, though mapped as structurally continuous with the country rock envelope (Taylor, 1969), is gneissic and highly fractured.

III Internal Structures in the Granites

The major part of the South Mountain batholith (i.e. biotite granodiorite) rarely displays any internal structures. Potassic feldspar phenocrysts occasionally have crude E-W or NE-SW orientations, but more often than not display no preferential alignment.

Alkali feldspar phenocryst alignments are more common in the adamellitic rocks. One textural phase of adamellite contains an average of 25% lath-shaped potassic feldspar phenocrysts which are often oriented. Various directions (including vertical) have been recorded, but again E-W and NE-SW alignments are most prevalent (poor outcrop quality has generally hampered the determination of plunges on these grains). In addition, xenoliths are usually oriented parallel to the phenocrysts, indicating that the alignment is a primary structure (Balk, 1937). It has also been observed that, within a single outcrop, the directions of phenocryst alignment may swirl and turn through various orientations. Moreover, alignments of the alkali feldspar may disintegrate into random orientations over a few meters. Thus, it would appear that local convective motion was the dominant process of alignment, whereas flowage parallel to the long axis of the batholith (and hence regional structural trends) was operative but of lesser importance.

A one kilometer wide, band of gneissic augen granodiorite, outcropping north of Trout Lake, Anna. Co. (Map 1, map unit 3a), also exhibits directional structures. Bands of biotite envelop oval plagioclase augen which are elongate in the direction of the bands. The mineral lineations range from NE-SW to ENE-WSW.

The augen granodiorite lies between biotite granodiorite to the north and a porphyritic member of the West Dalhousie adamellite (Chapter 4) to the south. The augen granodiorite/adamellite contact as well as the potassic feldspar phenocrysts within the adamellite also have a general NE-SW orientation. It is conceivable that the intrusion of the admellitic magma was responsible for imparting a gneissic structure to the granodiorite. However, as augen granodiorite has not been observed in other areas of the batholith in contact with adamellitic rocks and since its age relative to the structureless biotite granodiorites is unknown, it may post-date the adamellite intrusion. In this case the origin of the gneissic structure is unknown.

IV Joint Data

The orientation of a total of 566 joints and small shear planes plus 134 pegmatites, aplites and quartz veins were measured throughout the thesis area. These data are presented in Figures 2.1 and 2.2, respectively. The joint stereogram suggests that there are at least two and perhaps three nearly-vertical joints sets. The major trend is NE-SW with less important sets striking NW-SE and NNW-SSE. The joints sets may correspond to Balk's (1937) longitudinal(S), cross (Q), and diagonal joints, respectively. As required by Balk's definitions, all three are cooling features related to the direction of maximum lengthening or flowage in the batholith. Cross joints are perpendicular to this direction, longitudinal joints parallel and diagonal joints, which often occur in conjugate pairs, are oblique to the primary flow direction. However, assigning joints sets to this classification depends on a reliable determination of flowage direction within a pluton. On a regional scale the necessary correlation appears to exist, but as oriented fabrics are rather rare in the South Mountain batholith, the origin of the joints is still a matter of speculation.

Figure 2.1 also indicates that there is a sub-horizontal joint set. Volume changes due to contraction, decreases in load pressure and/or sub-horizontal flow layering may be the principal causes of this type of jointing.

The plot of quartz vein and aplite and pegmatite dyke attitudes is in some respects similar to the joint diagram. The vein and dyke data, however, show a N-S system which is not present in Figure 2.1. Conceivably, the vertical jointing and dyke/vein intrusion were penecontemporaneous, inter-

Figure 2.1: Plot of poles of joint planes for the South Mountain batholith.Points plotted on the lower hemisphere of an equal area net.

Explanation:

- 0-1%
- 1-3%
- 3-5%
- > 5%

Figure 2.2: Plot of poles of aplite and pegmatite dykes and quartz veins from the South Muontain batholith. Points plotted on the lower hemisphere of an equal area net.

Explanation:

- .75-3%
- 3-6%
- 6-9%
- > 9%

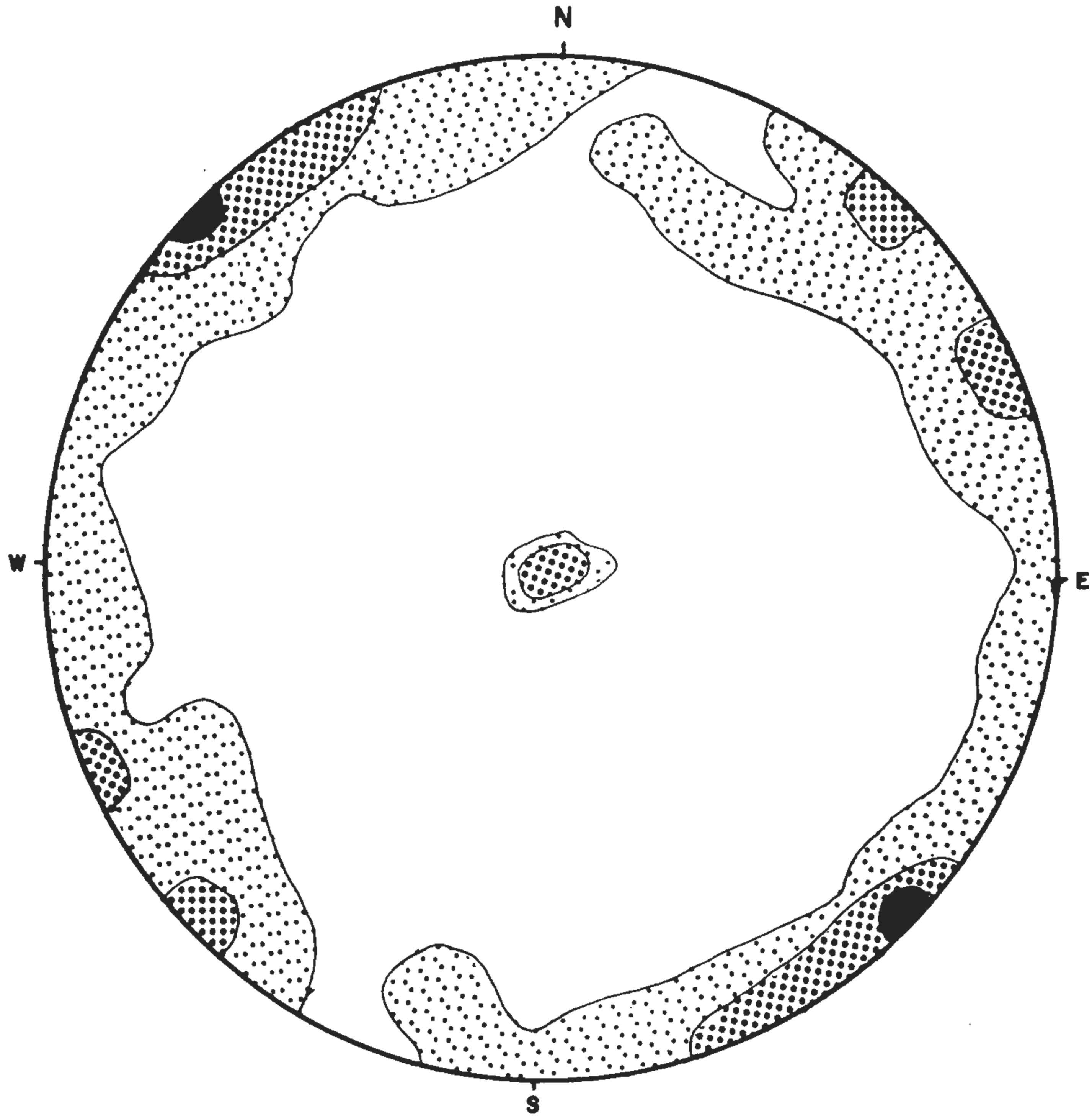


FIG. 2.1

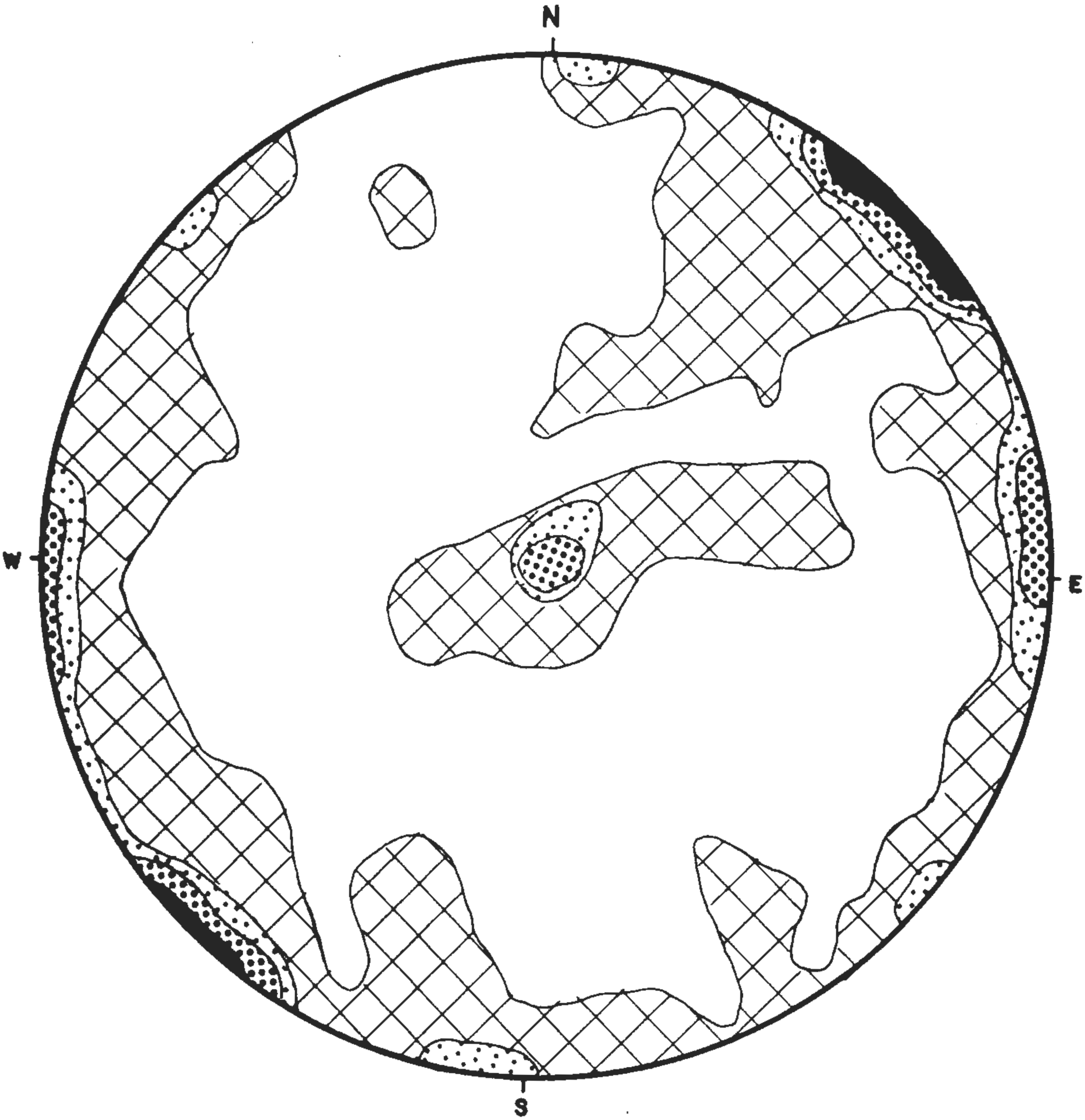


FIG. 2.2

dependent processes related to the final stages of batholith emplacement. Nevertheless, the data do not exclude the possibility of unrelated origins for these features.

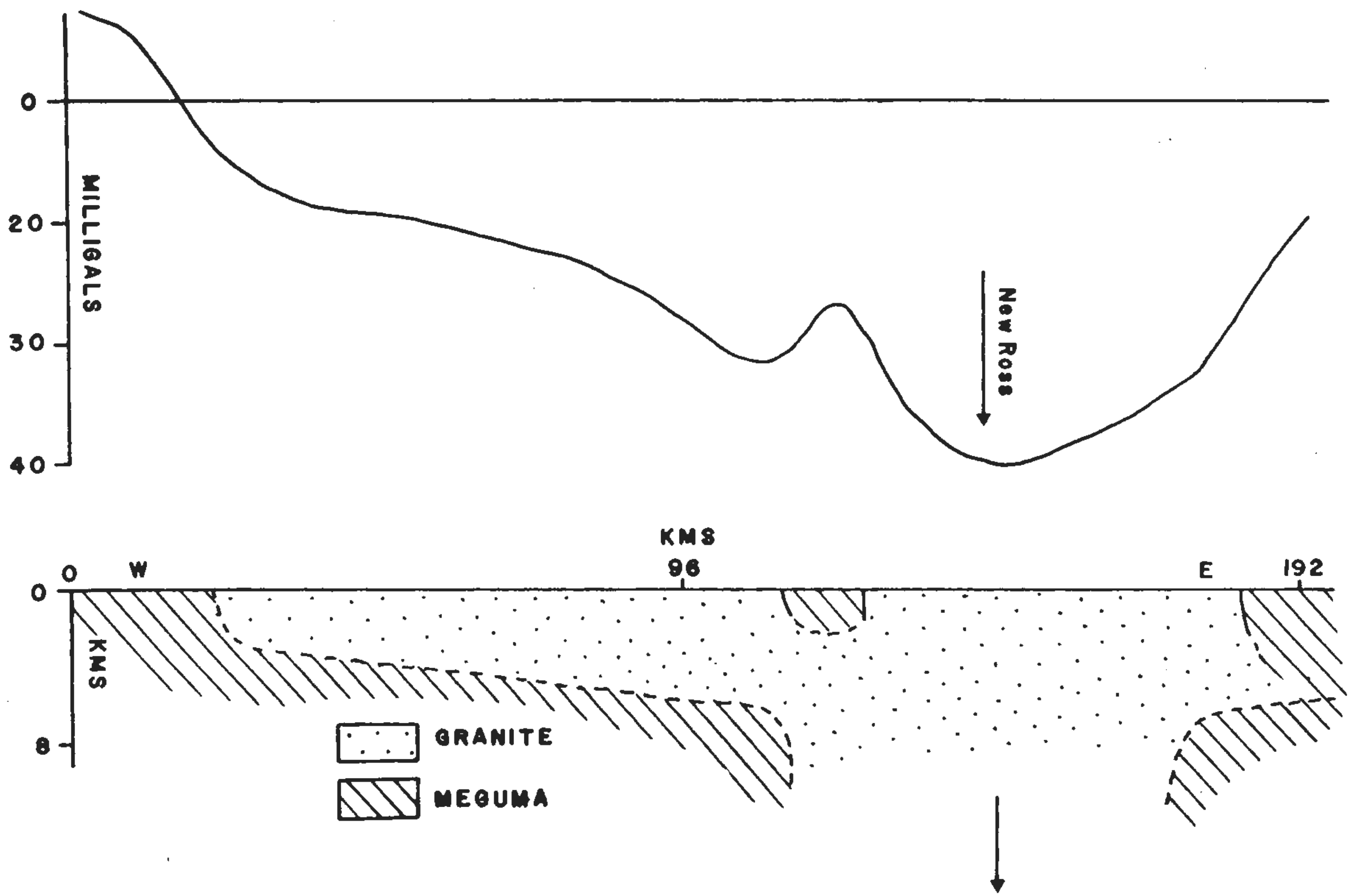
V Geophysics

Gravity and magnetic measurements have been made over western Nova Scotia by Garland (1953). His data suggest that the South Mountain batholith has an overall funnel or anvil shape (Fig. 2.3). Most of the pluton is in the form of a 5 km. thick slab, which thickens in the New Ross area to produce a cylinder of granitic material 55 km. in diameter and at least 17 km. deep. Magnetics over the granitic rocks are relatively "quiet", but also record a negative anomaly over New Ross.

The funnel-like or anvil-like shape is not unusual for high-level granitic plutons (Biehler and Bonini, 1969; Ager et al., 1972). Similar forms have been produced experimentally by Grout (1945) and Ramberg (1967, 1970). A consideration of this experimental data and its significance to the mode of emplacement of the batholith is given in Chapter 6.

It is also interesting to note that regional heat flow and heat production are generally highest in the New Ross area (Rankin, unpubl. Ph.D. dissertation) and are at least spatially associated with the negative gravity anomaly. In addition, all Sn, W, Mo and related mineralizations fall within or very close to the -500 milligal gravity contour (Fig. 2.4). The implications of these observations are

Figure 2.3: East-west gravity profile across the South Mountain batholith(after Garland,1953). The gravity model shows a cylinder of low density, granitic rock aprroximately 55 km in diameter and 17 km deep centred about New Ross,Lunenburg Co.



0
20
30
40
MILLIGALS
New Ross
KMS
0
W
96
E
192
0
KMS
8
GRANITE
MEGUMA

FIG. 2.3

Figure 2.4: The South Mountain batholith, showing the New Ross-Vaughn complex and mineral localities in relation to the gravity contours (after Garland, 1953).

Explanation:

- South Mountain batholith
- New Ross-Vaughn complex
- Gravity contours (milligals)
- Sn, W or Mo mineralization

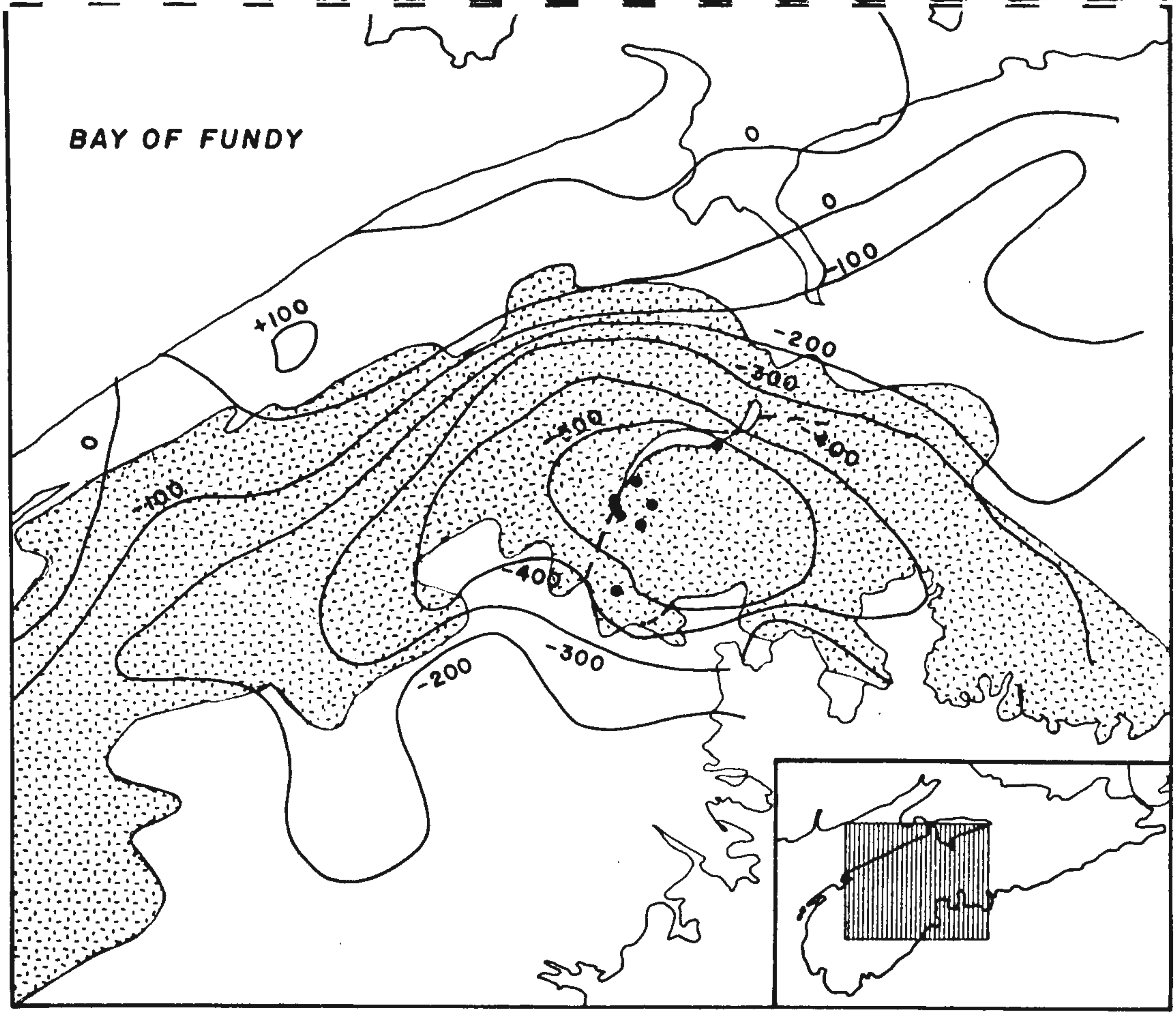


FIG. 2.4

discussed in Chapter 8.

VI Summary

The South Mountain batholith ascended into prefolded Paleozoic sequences as a bulbous, mushroom-shaped diapir. The parallelism of the long direction of the body to the regional Acadian trends and other structural data imply that emplacement was at least partially controlled by the pre-existing trends. However, the granitic invasion was apparently not a forceful event as fold structures are rarely deformed by the intrusives and directional fabrics in the granitic rocks are essentially absent.

CHAPTER 3: THE GRANODIORITES

I Introduction

Biotite granodiorite is the most abundant phase in the South Mountain batholith. Characteristically, the rock is light grey to grey in colour, has a coarse-grained, hypidiomorphic-granular groundmass and is mottled by large, whitish alkali feldspar phenocrysts. Biotite is the only mafic mineral of importance. The granodiorites contain abundant metasedimentary xenoliths in various states of recrystallization and assimilation.

Chemically, the biotite granodiorites are the least silicic phase of the pluton. Relative to the other granitic rock types found within the thesis area, the granodiorites are enriched in TiO_2, Fe_{Total}, MgO and CaO and are depleted in SiO_2 and K_2O. The trace element data also illustrates the relatively undifferentiated nature of the granodiorites.

II Definition of Granodiorite

The biotite granodiorites are recognized on the basis of two petrographic criteria. First, these rocks contain biotite as the only essential mica. Indeed, it is the only ferromagnesian mineral of any importance. Muscovite may occur as an alteration product, but primary muscovite is absent from the granodiorites. Secondly, the plagioclase generally constitutes about 67% of the feldspar content. However, rocks with considerably lower plagioclase components are still considered as biotite granodiorites if their texture and mineralogy (e.g. one mica) make them otherwise indistinguishable from the true granodiorites. These lithologies with slightly less than the required amount of plagioclase will be referred to as transitional biotite granodiorites.

III General Petrography

The groundmass of the biotite granodiorites is generally coarse-grained (see Appendix A) and hypdiomorphic-granular (i.e. granitic) in texture. It consists of quartz, plagioclase and biotite with lesser amounts of alkali feldspar and accessory apatite, zircon and opaque minerals.

Quartz, on the average, comprises 31% of the rock (see Table 3.1). It forms anhedral to subhedral, equant grains or grain aggregates and occasionally contains small biotite and/or plagioclase inclusions.

Plagioclase is andesine in composition; optical determinations indicating a range from An_{30}-An_{35}. Oscillatory, normal and patchy zoning are ubiquitous. The more calcic compositions in the grain cores give way to clear, normally zoned sodic rims which occasionally display myrmekitic quartz intergrowths. Small inclusions of biotite, and to a lesser extent quartz, are present in many grains. Sericite alteration is common but usually confined to the calcic cores.

The biotite, which modally averages 12.5%, occurs as subhedral to euhedral grains that enclose zircon (with pleochroic haloes), apatite and opaque minerals. Alteration to chlorite plus magnetite and, to a lesser degree, epidote or muscovite may occur, but generally the biotite appears unaltered. Amphiboles or other ferromagnesian minerals have not been found in the granodiorites.

Alkali feldspar phenocrysts (average Or_{94})[1] comprise 5% of an average biotite granodiorite. The phenocrysts are present as euhedral laths or stout, subhedral prisms that range from 2 to 10 cm. in length (average length: 3 to 4 cm.) and sometimes display a crude NE-SW or E-W alignment. The grains are characterized by perthitic intergrowths, Carlsbad twinning and occasionally microcline grid twinning. Inclusions of zoned plagioclase, biotite and quartz are abundant and frequently outline concentric growth zones within the phenocryst. Kaolinite and muscovite alteration are the normal secondary minerals. In the groundmass, alkali feldspar grades from phenocryst-size to small, interstitial grains which may poikilitically envelop other groundmass minerals.

Zircon, apatite and opaque minerals are the predominant accessory minerals. Generally all three are poikilitically enclosed in biotite, but the apatite and opaques may also exist independently. Garnet (almandine ?) occurs as a rare accessory mineral.

Metasedimentary xenoliths constitute an important part of the granodiorites. Primary bedding features and

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[1]Alkali feldspar compositions have been determined on the host only and do not include lamellae compositions.

angular corners are sometimes preserved, but most xenoliths are rounded and hornfelsed. The inclusions are fine to medium-grained, equigranular and may have developed a few small (.5 to 2 cm.) potassic feldspar porphyroblasts. The overall mineralogy is granitic: quartz, plagioclase and biotite are the chief constituents while alkali feldspar is present in lesser amounts. Accessory minerals are also similar to those of the host rock; excepting the more common appearance of garnet and one isolated occurrence of sphene. At present, there is no way in which to identify the source of any one xenolith. Most appear as biotite-rich enclaves and retain no features characteristic of the original sedimentary rock. It may be possible to distinguish psammitic (e.g. Goldenville Formation) xenoliths from pelitic (e.g. Halifax Formation) inclusions by their metamorphic paragenesis, but there has not yet been a sufficient number of xenoliths investigated to either prove or disprove this. A further complicating factor is the presence of similar sand and shale lithologies not only in the Goldenville and Halifax Formations but also in the Siluro-Devonian sequences.

The distribution of xenoliths within the biotite granodiorites does not seem to be a function of proximity to the observed contacts. Granodiorites from the centre of the batholith are not significantly poorer in metasedimentary inclusions than those near the perimeter. This suggests that most xenoliths have been stoped from the roof zone of the pluton and that little material has been contributed from the walls.

In the area south of Greenwood, Kings Co., the granodiorites are crowded with large, rounded xenoliths. This is also an area of several structurally conformable, metasedimentary inliers (Smitheringale, 1973). Thus, the local level of exposure may be nearly coincident with the roof of the batholith.

IV Petrographic Variations

The coarse-grained variety of biotite granodiorite apparently undergoes a decrease in grain size in various parts of the batholith, thus producing a distinctly medium-grained phase. The change in grain size does not seem related to the proximity of the metasedimentary contacts. Moreover, no characteristic changes in mineralogy or chemistry accompany the grain size reduction.

Two other types of granodiorite of rather restricted occurrence are also present in the South Mountain batholith. The augen granodiorite north of Trout Lake, Annapolis Co. has been discussed in Chapter 2. Except for the occurrence of primary (?) muscovite, the phase is mineralogically similar to the normal biotite granodiorites. The oriented fabric and plagioclase augen are the unique features of this granodiorite.

Also mentioned in Chapter 2 were the contact facies granodiorites found intimitely associated with two small metasedimentary inliers. In general, the rock is medium-grained or has a bimodal grain size distribution between a fine- to medium-grained groundmass and a coarse-grained porphyritic constituent (plagioclase and quartz). The overall mineralogy is similar to the more typical biotite granodiorites, with the exception of relative enrichments in biotite and apatite (Table 3.1).

The contact facies granodiorites have been highly contaminated by metasedimentary material. Not only are there plentiful xenoliths of various shapes, but also it frequently appears that there has been an intermingling of igneous and sedimentary material on a grain to grain scale. The intermingling accounts for the analyzed contact facies granodiorite having the lowest SiO_2 percentage and the highest Fe_{Total} and MgO levels of all the rocks studied chemically (see Meguma quartzite analysis; Wright, 1931). Thus assimilation appears to have played an important role in the development of this peculiar granodiorite phase.

In at least two parts of the thesis area the biotite granodiorites apparently grade into a transitional granodiorite phase. South of the contact between the intrusives and country rocks on Route 10 the phase is medium- to coarse-grained, subporphyritic and contains a few xenoliths. The alkali feldspar content, which is greater than that of the biotite granodiorites, appears to increase towards the contact (i.e. northwards) while the biotite content decreases. Muscovite, however, is still present only as a secondary mineral.

Similar rocks occur in the Seffern Lake, Lunen. Co., area along Route 12. Again the phase is medium- to coarse-grained, subporphyritic and xenolith-bearing, with more alkali feldspar and less biotite than typical biotite granodiorite. However, unlike the transitional rocks further west, these show evidence of post-magmatic, hydrothermal activity. Plagioclases are extensively altered, alkali feldspar has much associated muscovite and quartz veins are locally abundant. Also tourmaline occurs as a rare accessory.

Although only one analysis exists for the transitional granodiorites (see M72-127, Table 3.2) the data suggest that these lithologies are the result of differentiation. From the major element chemistry, it can be seen that SiO_2 and K_2O levels are up from most of the granodiorites whereas Fe_{Total}, MgO and CaO levels are down. The trace element chemistry is also demonstrative of increasing fractionation. Zirconium, tin and barium concentrations are among the lowest of any granodiorite. On the other hand, Rb and Sn, elements concentrated by increasing differentiation, are relatively abundant. Thus, the transitional rocks may be the final crystallates of the granodioritic magma.

V Chemistry

The major and trace element chemistry, along with the normative and modal compositions, of all analyzed granodiorites (and transitional granodiorites) are given in Tables 3.1 to 3.3. The granodiorites comprise the least silicic rocks of the batholith and this is illustrated by the relatively low SiO_2 and K_2O percentages coupled with relatively high Fe_{Total}, TiO_2, MgO and CaO levels. Chemical variations within the granodiorites correspond to those noted in the previous section. Systematic geographic changes in granodiorite geochemistry such as might be found in the K_2O index (Figures 3.1 and 3.2, Table 6.1), are not indicated by the present data.

The trace element data also confirms the basic chemical character of the granodiorites. Zirconium concentrations are high as are those of Sr and Ba, and these elements vary antipathetically with increasing differentiation (Taylor, 1965). Not unexpectedly Rb, which is similar to K, is relatively depleted in these rocks.

The norm calculation shows that all the granodiorites are peraluminous (i.e. corundum normative). Moreover, the normative differentiation index varies from 74.4 to 84.3 whereas the colour index encompasses a range from 13.4 to 7.0. A complete discussion of the norm and chemical data in relation to the other granitic phases is given in Chapter 6.

VI Summary

Biotite granodiorite, in addition to being the most voluminous phase of the South Mountain batholith, is the least differentiated and probably the oldest phase as well. It is characterized from the later lithologies by the presence of only one mica (biotite) and the predominance of plagioclase over alkali feldspar. There is indication that some local differentiation has gone on within the grano-

Figure 3.1: Variability of the K_2O index for biotite granodiorites parallel to the long axis of the South Mountain batholith. Horizontal scale as in Figure 1.1.

Figure 3.2: Variability of the K_2O index for biotite granodiorite perpendicular to the long axis of the South Mountain batholith. Horizontal scale as in Figure 1.1.

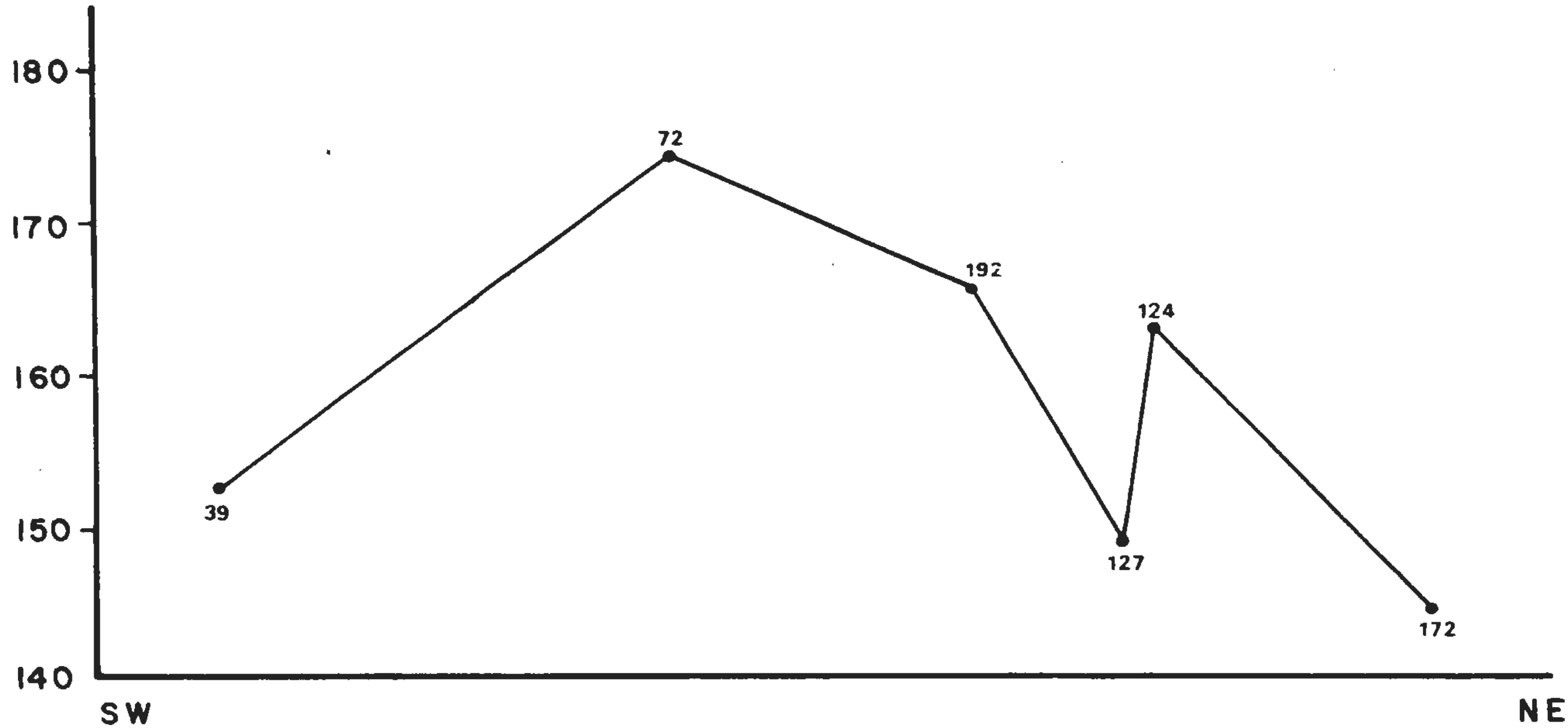

FIG. 3.1

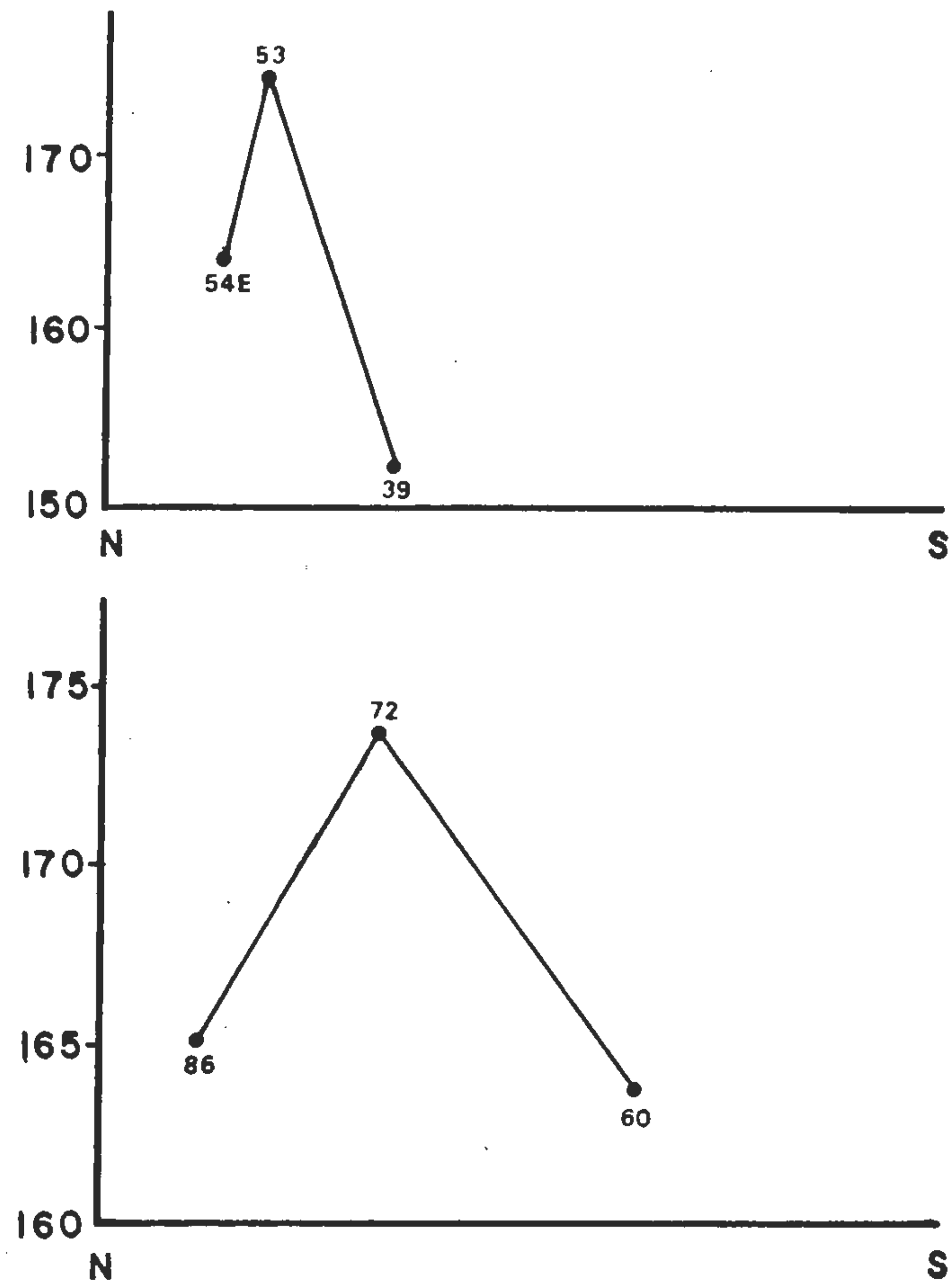

FIG. 3.2

diorites, but at the present level of knowledge, they are considered to form a chemically and petrographically homogenous body of rock.

Table 3.1

Modal analyses (in volume per cent) of chemically analyzed biotite granodiorites

Sample No.	M72-39	53	54E	60	72	86	124	127	137	172	192
Quartz	36.0	33.5	26.4	35.3	41.4	28.8	30.7	32.1	25.8	33.1	33.9
Plagioclase	37.0	37.5	49.4	39.0	31.3	36.0	38.1	33.0	42.6	36.0	33.2
K-Feldspar	16.5	9.3	7.3	12.2	16.3	21.4	16.4	23.0	16.4	21.0	19.4
Biotite	10.4	19.3	16.9	13.5	10.8	13.8	14.8	8.2	15.2	9.2	14.5
Muscovite	-	-	-	-	-	-	-	3.4	-	.7	-
Accessories	-	-	-	-	-	-	-	.4	-	-	-

Table 3.2

Chemical analyses of biotite granodiorites

mple No.	M72-39	53	54E	60	72	86	124	127	137	172	192
jor elements (%)											
iO_2	70.3	67.4	66.8	70.4	68.6	70.0	68.8	72.2	68.2	70.9	69.6
iO_2	.61	.72	.81	.54	.61	.55	.68	.42	.68	.44	.61
l_2O_3	13.63	14.65	14.41	14.42	14.66	14.71	14.52	14.26	14.52	14.08	14.14
e_2O_3	.50	.33	.87	.47	.23	.59	.45	.26	.45	.29	.43
O	3.47	4.20	4.71	2.62	3.78	3.45	3.88	2.52	3.88	2.48	3.78
O	.09	.10	.13	.09	.10	.10	.10	.09	.10	.10	.10
gO	.89	1.24	1.41	.74	.98	.85	1.18	.75	1.18	1.03	.99
O	1.72	2.28	2.28	1.72	1.93	1.78	2.21	1.44	2.21	1.84	1.82
$_2O$	3.14	3.29	3.32	3.47	3.34	3.72	3.18	3.31	3.18	3.08	3.13
O	3.85	3.90	3.57	4.16	4.10	4.13	3.46	4.04	3.46	3.73	4.08
$_2O^+$	1.08	.84	.98	.56	.89	.94	.91	.88	.94	.93	.76
$_2O_5$	.05	.14	.10	.12	.08	.08	.10	.16	.10	.02	.14
tal	99.33	99.09	99.39	99.31	99.30	100.90	99.21	100.33	98.90	98.92	99.58
ace elements (ppm)											
n	10	8	15	10	10	12	7	18	8	15	16
b	156	130	123	162	148	172	143	174	132	136	144
r	118	176	144	114	146	117	156	112	174	154	111
a	619	856	760	632	732	672	668	429	738	618	616
r	196	253	267	175	204	218	210	168	260	120	198
n	72	74	82	60	70	68	71	60	68	53	68
i	16	18	22	12	16	15	16	12	20	14	16
r	54	56	58	42	52	51	50	42	59	52	56

Table 3.3

CIPW Norms of analyzed biotite granodiorites

Sample No.	M72-39	53	54E	60	72	86	124	127	137	172	192
Quartz	30.62	24.48	24.38	28.50	25.80	25.36	27.23	32.12	28.16	32.20	28.49
Orthoclase	23.18	23.48	21.46	24.92	24.64	24.44	23.28	24.03	20.89	22.51	24.42
Albite	27.04	28.33	28.54	29.73	28.72	31.49	27.27	28.16	27.47	26.59	26.80
Anorthite	8.35	10.58	10.83	7.85	9.20	8.31	9.89	6.13	10.52	9.18	8.21
Hypersthene	7.47	9.69	10.51	5.61	8.51	7.25	9.25	5.79	8.94	6.47	8.33
Magnetite	.74	.49	1.28	.69	.34	.86	.37	.38	.67	.43	.63
Ilmenite	1.18	1.39	1.56	1.04	1.18	1.05	1.35	.80	1.32	.85	1.17
Apatite	.12	.33	.24	.28	.19	.19	.14	.37	.24	.05	.33
Corundum	1.31	1.23	1.20	1.38	1.43	1.07	1.22	2.22	1.80	1.71	1.62
Differentiation Index	80.8	76.3	74.4	83.1	79.2	81.3	77.8	84.3	76.5	81.3	79.7
Colour Index (wt pct.)	9.4	11.6	13.4	7.3	10.0	9.1	11.0	7.0	10.9	7.8	10.1

CHAPTER 4: THE ADAMELLITES

I Introduction

Adamellitic rocks comprise approximately 25% of the South Mountain batholith. The adamellites occur in four large plutons and one minor body. From west to east the major masses have been named the West Dalhousie adamellite, Springfield Lake adamellite, Lake George adamellite and New Ross-Vaughn complex, respectively. Ranging in size from 120 km^2 to 500 km^2, the bodies are irregularly shaped and apparently spatially independent of one another. Generally, each pluton is made up of several texturally distinct phases, most of which are common to two or more of the adamellite bodies.

The adamellites differ petrographically from the biotite granodiorites in several ways. Potassic feldspar is generally the predominant feldspar while biotite is less abundant than in the granodiorites. More important, however, is that muscovite occurs as an essential mineral. Also characteristic of the adamellites is the paucity of xenoliths, the appearance of andalusite as an accessory mineral and locally extensive hydrothermal alteration.

Chemically, the adamellites are more silicic than the biotite granodiorites. Hence, the adamellitic levels of SiO_2 and K_2O are higher, and TiO_2, Fe_{Total}, MgO and CaO levels are lower, than those of the granodiorites. The chemical data, when considered with the petrography and field relations, suggest that the adamellites are more differentiated than the granodiorites and are thus later in the intrusive history of the batholith.

II Definition of Adamellite

Adamellites of the South Mountain batholith, although texturally rather variable, are recognized on the basis of two petrographic criteria:

1. they possess both biotite and muscovite as essential minerals;
2. plagioclase constitutes from 33% to 67% of the total feldspar content.

In most of the adamellites plagioclase does not exceed 50% of the feldspar content. Thus, there is generally no overlap with the feldspar constitution of the transitional granodiorites.

III General Petrography and Field Relations

Four large pods and one minor body of 2-mica adamellitic rocks have been mapped within the thesis area. From west to east the larger bodies are:

1. West Dalhousie adamellite
2. Springfield Lake adamellite
3. Lake George adamellite
4. New Ross-Vaughn complex

The small adamellite body, designated the Morse Road adamellite (Fig. 1.1, #2), is discussed in Chapter 5. A summary of the characteristics of each adamellite pluton is presented in Table 4.1.

For the most part the adamellite pods are enclosed in biotite granodiorite. However, no exposed granodiorite/ adamellite contacts were located in the field. Accordingly, age and intrusive relations are not available from direct observation. These contacts may be sharp since no transition zones or recognizable inclusions of one granitic type within another have been found in the proximity of inferred contacts. In several areas, adamellite pods are in contact with the metasediments. These relations have been described and discussed in Chapter 2.

Although several texturally distinct phases are present, the adamellite bodies share a number of common features. The adamellites are generally more altered than the biotite granodiorites. Buff and pinkish colours in the feldspars are common and biotites are often altered to chlorite and, to a lesser extent, epidote or muscovite. A scarcity of metasedimentary xenoliths is another characteristic common to all adamellitic phases. The rare xenoliths present are small, rounded and completely recrystallized. The third feature shown by each of the bodies is the presence of andalusite as an accessory mineral. This is an unusual accessory for granitic rocks and its occurrence has significant petrogenetic implications. A full discussion of the importance of this mineral is given in Chapter 6.

IV West Dalhousie Adamellite

The West Dalhousie adamellite is an elongate body of some 300 km^2 in area. The pod extends from south of Annapolis Royal to south of Middleton in a direction subparallel to the long axis of the batholith. Three distinct textural phases make up the adamellite pluton; porphyritic adamellite, non-porphyritic adamellite and medium-grained leucoadamellite. The adamellites are gradational into one another and apparently represent textural variations of a single intrusive event. The remaining phase, an albitic leucoadamellite, post-dates the first two and is discussed more fully in Chapter 5. The approximate distribution of phases within the body is shown in Fig. 4.1.

Porphyritic adamellite is the most abundant phase within the West Dalhousie pod. It is medium- to coarse-grained, has a hypidiomorphic-granular groundmass and contains abundant lath-shaped phenocrysts of alkali feldspar. Quartz, potassic feldspar, plagioclase, biotite and muscovite are the essential minerals of the rock while apatite, zircon and opaque minerals are the common accessories (modes in Table 4.1). In general, the rock is greyish but occasionally the feldspars are buff or pinkish in colour.

Quartz occurs as anhedral to subhedral grains and grain aggregates which range from a few mm. to 1 cm. in the long direction. Small biotite crystals are occasionally present as inclusions.

Plagioclase is present as 2 mm.-10 mm. subhedral grains which frequently display oscillatory and normal zoning. Patchy zoning is less common. None of these features

Figure 4.1: Geologic map of the West Dalhousie adamellite.

Explanation:

- Greywood leucoadamellite
- Non-porphyritic adamellite
- Porphyritic adamellite
- Augen granodiorite
- Biotite granodiorite

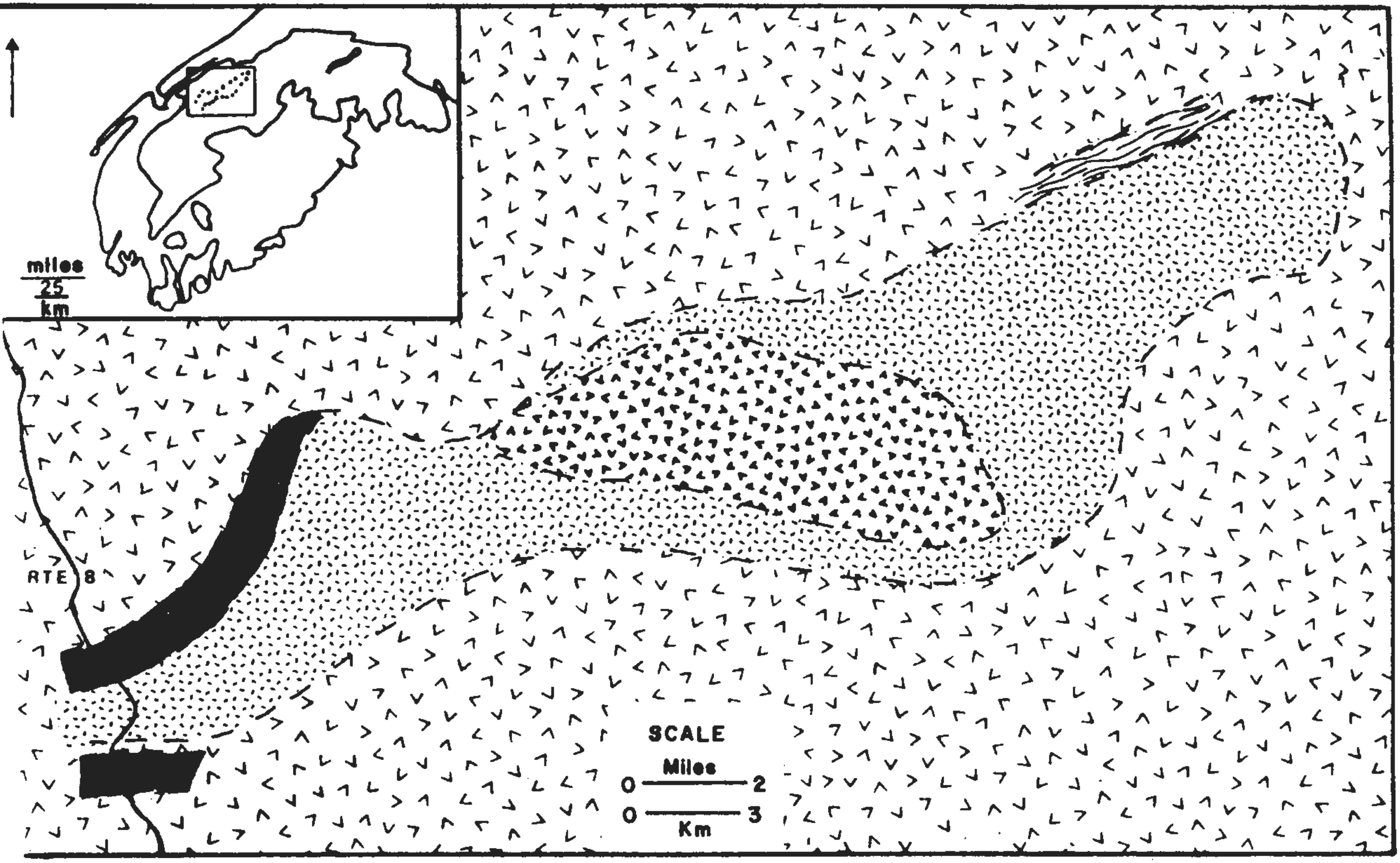

FIG. 4.1

are as common as in the biotite granodiorites, nor are they always as well-developed. Compositions range from andesine (An_{30-32}) in the grain cores to sodic oligoclase or albite at the margins. The cores are often the sites of extensive sericitization whereas the sodic rims remain clear and unaltered. Some grains contain small biotite inclusions; others may have their margins intergrown with myrmekite.

Alkali feldspar (Or_{93}) is the more abundant feldspar in this phase of adamellite and is both a phenocryst and groundmass constituent. The phenocrysts, which are generally lath-shaped (although some blocky, subhedral megacrysts may also be present) and preferentially aligned, comprise 15% to 25% of the rock. Sizes range from 1 to 6 cm, the average length being 2 to 3 cm. The phenocrysts are microcline perthites and often contain a great number of small concentrically arranged inclusions of quartz, plagioclase and mica. Rapakivi textures (i.e. the mantling of alkali feldspar by plagioclase) are occasionally observed.

Groundmass alkali feldspars are less poikilitic than the megacrysts, but like the larger crystals have exsolution textures and grid-twinning. Unlike the groundmass alkali feldspar of the biotite granodiorites, this mineral rarely shows interstitial relations with the other groundmass constituents. Kaolinite and muscovite are the common alteration products.

Biotite is generally the dominant mica of the porphyritic adamellites, but its relative abundance is reduced from the biotite granodiorites. Often it is crowded with haloed zircon inclusions which sometimes outline concentric zones within the biotite. Apatite and opaque minerals are less frequent inclusions. Alteration to chlorite has been observed, but most grains appear "fresh" and unchanged. Muscovite occurs not only as a primary mineral, but also as a secondary mineral after the feldspars and biotite.

Accessory minerals consist primarily of zircon, apatite and opaque minerals. These are usually associated with biotite although the latter two may exist independently. Andalusite, enveloped in muscovite, is a rare accessory and has only been observed from the western end of the West Dalhousie body.

Xenoliths constitute a minor part of the rock. They are generally rather small (maximum length 16 cm), rounded and recrystallized. Small alkali feldspar porphyroblasts have been developed in a few inclusions. Frequently the long directions of the xenoliths are subparallel the phenocryst orientation. Clusters of biotite, 2 cm to 3 cm long, are also present and these may represent the last refractory residue of assimilated metasedimentary material.

Although the field relations have not been fully mapped, the porphyritic adamellite appears to enclose a non-porphyritic phase centred about West Dalhousie, Annapolis Co. Contacts between the two phases are distinct, but interdigitating rather than intrusive in nature. The non-porphyritic rock is medium- to coarse-grained and granitic in texture. Colour ranges from light grey to buff and pinkish. The latter tones may be due to local dyke intrusion, but such relations are not always obvious.

Mineralogically, the phase is rather similar to the porphyritic adamellite. Plagioclase is andesine (An_{31}) in composition and distinctly zoned. Alkali feldspars are perthitic and enclose small plagioclase, quartz and mica grains; however, the inclusions lack the concentric zonal symmetry shown by those in the phenocrysts of the porphyritic phase. Apatite, zircon, opaques and rare andalusite make up the accessory minerals.

Metasedimentary inclusions are not common and are characterized by the features described for xenoliths of the porphyritic adamellite.

The two minor intrusive bodies spatially associated with the West Dalhousie adamellite (Fig. 4.1) are compositionally albitic leucoadamellites. Accordingly, their discussion is reserved for Chapter 5.

V Springfield Lake Adamellite

The Springfield Lake adamellite outcrops over an area of roughly 150 km^2 along the south margin of the thesis area (Fig. 1.1). It is arcuate in shape and has its long axis generally parallel to that of the batholith. The pod is encircled by biotite granodiorite except on the southern side where it appears to be in contact with the Meguma metasediments. Unfortunately, neither granodiorite/adamellite nor metasediment/adamellite contacts have been found in outcrop.

The pluton is comprised of three phases which are texturally, if not compositionally, equivalent to the lithologies described in the preceding section. However, further mapping is required in order to define the geographic distribution of each rock type.

A porphyritic member is apparently confined to the western end of the body. It is frequently buff grey but may also be light grey in colour. The mineralogy is similar to the porphyritic adamellites of the West Dalhousie pod. However, the plagioclases differ from those further west by having smaller calcic cores and broader sodic margins. Nevertheless, maximum anorthite contents are the same.

A medium- to coarse-grained, equigranular, subporphyritic (phenocryst composition, Or_{96}) to non-porphyritic phase is found throughout the Springfield Lake body. It is buff to orange grey in colour but locally may be pink or reddish. The rock is generally quite altered (e.g. sericitized plagioclase cores, chloritized biotite) but is otherwise petrographically similar to the West Dalhousie adamellites.

Leucoadamellitic and/or alaskitic bodies are also exposed within the Springfield Lake pluton. However, their areal distribution, petrography and chemistry are still imperfectly known.

VI <u>Lake George Adamellite</u>

The Lake George adamellite forms a kidney-shaped body that is centred about Lake George, Kings Co. It is approximately 120 km^2 in area and is the smallest adamellite pod in the batholith. All but the northwest corner of the pluton, which is in contact with Meguma metasediments, is enveloped in biotite granodiorite. No adamellite/granodiorite contacts have been observed; however, the adamellite/metasediment contact is relatively well-exposed along the Aylesford-Lake George Road.

The contact zone is .5 to 1 km wide and is transected by numerous aplite dykes. In addition, aplitic and adamellitic veins display both cross-cutting and lit-par-lit relations with the metasediments. The country rock is highly recrystallized, gneissic and in places shows evidence of mobilization in the form of convoluted gneissic textures. The adamellites in the vicinity of the contact undergo a slight reduction in the number of alkali feldspar phenocrysts, but apparently are neither texturally nor mineralogically altered by the proximity of the boundary.

Only one textural phase is present in the Lake Gecrge adamellite. The rock is medium- to coarse-grained, granitic in texture and contains up to 30% alkali feldspar phenocrysts. The colour varies from buff or brownish grey to pinkish grey. Occasionally the rock is sufficiently altered so as to make it quite friable. This phase is equivalent to the porphyritic members of the West Dalhousie and Springfield Lake adamellites.

Plagioclase compositions range from An_{28} to An_{30} (oligoclase/andesine) in the grain cores. The grains are frequently zoned (both oscillatory and normal) and have clear, sodic rims. The calcic cores are commonly completely sericitized and may also be reddened by occluded hematite dust. Biotite and quartz are occasional inclusions.

The alkali feldspar occurs in the groundmass and as euhedral, lath-shaped phenocrysts; subhedral stout prisms are less common. Possible colours include pale pink, pink or buff. The laths grade from groundmass size to 8 cm long (average 2 to 3 cm) and are often oriented E-W or NE-SW. However, the direction of alignment may vary greatly even within a single outcrop. Zoned plagioclase, quartz and mica inclusions are abundant in the phenocrysts and are frequently concentrically arranged. The alkali feldspar is also characterized by perthitic textures, microcline grid-twinning and secondary kaolinite, muscovite and hematite dust.

Biotite often contains numerous zircon inclusions, with apatite and opaque minerals being less common. Moreover, the zircons, which are usually encircled in pleochroic haloes, sometimes outline zones within the biotite. Muscovite is both a primary and secondary mineral. Some of the primary muscovite has been observed enclosing accessory andalusite.

Accessory minerals are generally found as inclusions in the micas. Andalusite, which is a rare accessory of the adamellite pods to the west, is more common in the Lake George body. Tourmaline has been found in small amounts. Xenoliths, as in the other adamellite plutons, are present but not common.

A few, small miarolitic cavities have also been noted in the Lake George pod. They are usually associated with aggregations of potassic feldspar crystals. Various workers (Buddington, 1959; Taylor, 1971; Taylor and Forester, 1971) have considered the cavities as characteristic of high level intrusions.

VII The New Ross-Vaughn Complex

The largest adamellite body in the South Mountain batholith is the New Ross-Vaughn complex (Fig. 1.1). It covers approximately 500 km^2 within the thesis area, but may constitute most of the granitic rocks lying to the east (Smith, 1973). The pod is comprised of a complex assemblage of 2-mica adamellites, later-stage minor intrusive bodies and numerous aplite, pegmatite and porphyry dykes. Several texturally distinct adamellite phases are present within the body, but as textures apparently vary within individual phases, only gross differences have been mapped. The distribution of adamellitic types is shown in Figure 4.2.

Much of the New Ross-Vaughn complex is extensively altered. An area of very intensely altered and reddened rocks occurs in the northeast corner of the body. Apparently, the alteration has not been confined to a particular textural type. Elsewhere in the pod rocks are less altered, but nonetheless may show evidence of considerable hydrothermal activity. Indeed, even "fresh-looking" adamellites, which are less common than the altered varieties, often prove to be quite altered when viewed under the microscope. Late-stage volatile activity is indicated by the presence

Figure 4.2: Geologic map of the New Ross-Vaughn complex. Dykes shown schematically.

Explanation:

- Aplites,pegmatites or porphyry dykes
- Minor intrusive bodies
  - 5.Lake Ramsay alaskite
  - 6.Leminster alaskite
  - 7.Lewis Lake leucoadamellite
  - 8.Card Lake alaskite
- Contact facies adamellite
- "Fresh" adamellite
- Non-porphyritic adamellite
- Medium-grained adamellite
- Porphyritic adamellite
- Biotite granodiorite
- Meguma Group

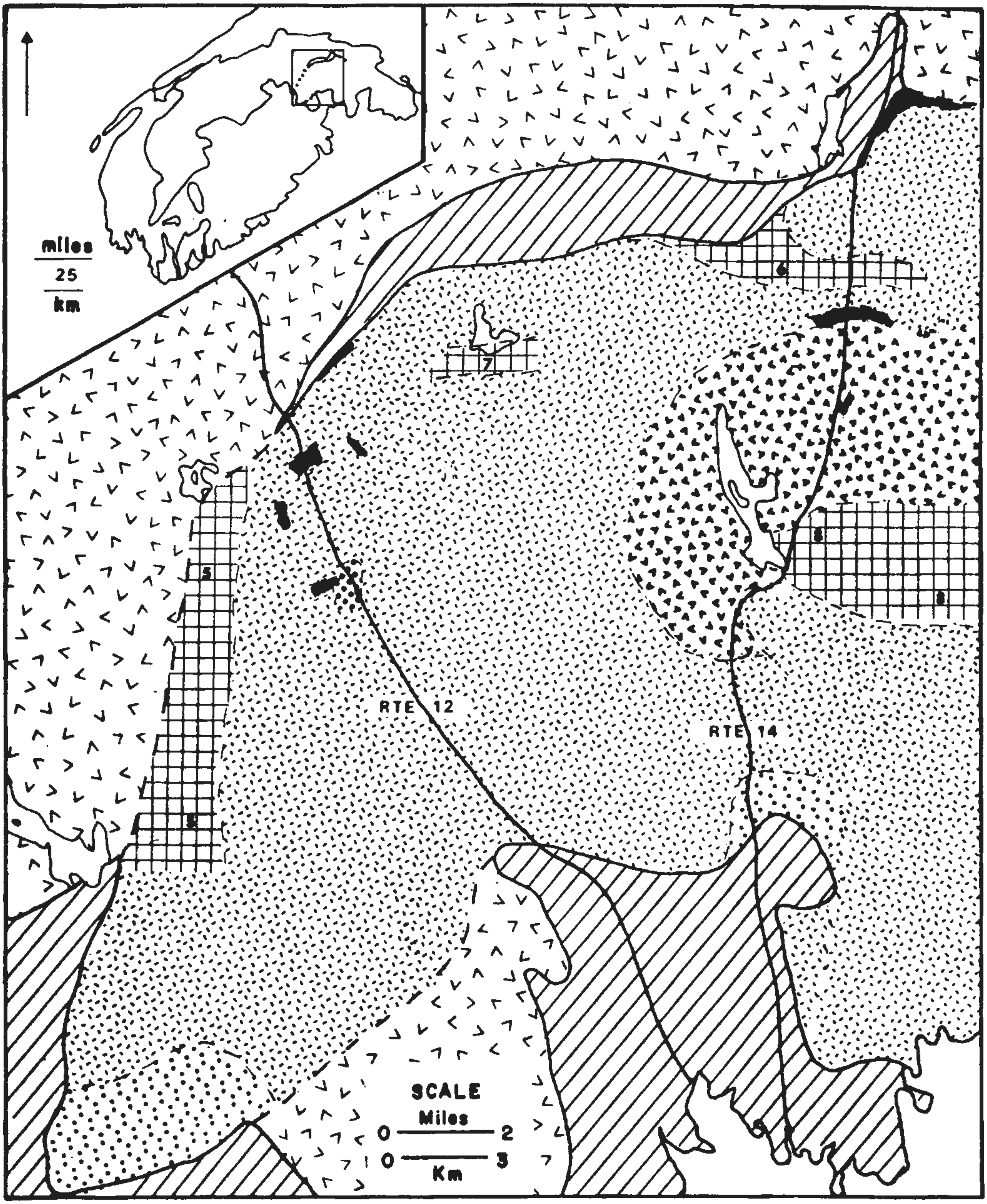

FIG. 4.2

of fluorite. This mineral occurs as a purplish smear on joint planes or in pegmatites and pegmatitic segregations.

Figure 2.4 demonstrates that the New Ross-Vaughn complex is closely associated with the low gravity feature described in Chapter 2. This map also shows that Sn, W, Mo mineralizations in the South Mountain batholith are restricted to the New Ross-Vaughn rocks. The significance of this association of textural variability, hydrothermal alteration, low gravity and mineralization is discussed in Chapter 8.

The most abundant phase in the New Ross-Vaughn pluton is a porphyritic adamellite. In many areas it is texturally indistinguishable from the porphyritic phases of the other bodies. The groundmass is medium- to coarse-grained and hypidiomorphic granular. Lath-shaped alkali feldspar megacrysts (compositions range from Or_{91} to Or_{98}), averaging 2 to 4 cm in length are abundant and often display parallel alignments. Rapakivi textures have also been noted. Colours vary from light grey in the relatively unaltered rocks to buff-, pinkish- or reddish-grey in the more altered varieties.

Plagioclase compositions of oligoclase/andesine in the "fresher" adamellites are similar to those in the porphyritic phases of the other plutons. However, in the altered lithologies there are two plagioclase compositions present. Oligoclase/andesine plagioclases, which appear as red grains in hand specimen, are often completely sericitized and hematized. Zoning features are usually obliterated, although in some instances the zones are still recognizable. Albitic plagioclases are normally smaller in size than the more calcic variety and do not show signs of alteration. Boone (1969) has suggested that the retention of hydrothermal fluids for a relatively long period after solidification can cause the chloritization of biotite, the formation of albite, and the hematization and sericitization of plagioclase. This may be the most plausible explanation of the phenomenon as it is difficult to envisage how such an abrupt change in feldspar composition could be effected by a magmatic fractionation process.

The other essential and accessory minerals are typical of the 2-mica adamellites in general.

The porphyritic phase grades imperceptibly into both phenocryst-rich and phenocryst-poor adamellites. The latter contain 1% to 5% phenocrysts, but are otherwise petrographically similar to the normal porphyritic type. The phenocryst-enriched varieties, however, are remarkable in that they are coarse-grained and contain 30% to 40% alkali feldspar megacrysts. The alkali feldspar crystals are large (average length 3 to 6 cm) and phenocrysts up to 11 cm long have been noted. Moreover, the megacrysts are generally well-formed laths or stout prisms and display preferred orientations. Mineralogically, this adamellite is also comparable to the normal porphyritic member.

On the east side of the thesis area (along Route 14), occurs a light grey, distinctly medium-grained adamellite

(Fig. 4.2). The groundmass is hypidiomorphic granular in texture and is composed of quartz, plagioclase, alkali feldspar, biotite, muscovite and minor accessories. Alkali feldspar phenocrysts (Or_{96}), generally in the form of euhedral laths, range from 0% to 10% of the rock; however, 1% to 3% is the common proportion.

The plagioclase composition in this rock is An_{34} in the grain cores, but since most grains are oscillatory- and normally-zoned, compositions become more sodic towards the margins. The calcic cores are frequently sericitized while rims remain clear. Biotite and occasionally quartz are observed as inclusions within the plagioclase.

Alkali feldspar is perthitic, may show microcline grid-twinning and frequently poikilitically encloses small grains of zoned plagioclase, quartz and mica. Grains of phenocryst size vary in length from 1 cm to 7 cm, the average being 2 cm to 3 cm. Rapakivi textures are present in this adamellite, as well. In addition, subhedral quartz grains or grain aggregates sometimes attain the minimum phenocryst size.

The biotite contains zircon, apatite and opaque mineral inclusions and some grains are chloritized. Muscovite is relatively abundant and may display reaction relations with andalusite.

As in the other adamellites, xenoliths are typically small, rounded, recrystallized and scarce.

In one locality, the medium-grained adamellite has been observed in sharp, but irregular contact with the porphyritic phase. Relative ages are difficult to assess; however, the medium-grained rock may be the younger of the two since the phenocrysts of the porphyritic adamellite are unaffected by the contact and often trend perpendicular to it. On the other hand, the phenocrysts would not necessarily have an orientation if the porphyritic phase had intruded a still hot and mobile medium-grained phase.

A medium- to coarse-grained, light grey adamellite outcrops on the Gold River in New Ross, Lunen. Co. (Fig. 4.2). Apparently, it is limited to a rather small area as equivalent rock types have not been observed in the immediate vicinity. This phase contains relatively few alkali feldspar phenocrysts (Or_{94}), 2 cm to 6 cm in length, and is free of metasedimentary inclusions. Its mineralogy is typical of the adamellites; plagioclases are zoned and attain a maximum composition of oligoclase/andesine in the sericitized grain cores. Biotite is often chloritized and has the normal inclusions. Muscovite occurs both as a primary and secondary mineral. Andalusite is a common accessory and is always mantled by muscovite. The alkali feldspar is perthitic and generally encloses plagioclase, quartz and mica grains; grid-twinning, however, is not developed.

The notable feature of this adamellite is its unaltered aspect in the field. In spite of the fact that it is more or less encircled by a pink porphyritic phase and that in thin section alteration is fairly extensive, the rock retains its light grey colour and "fresh" appearance.

Two, probably small, bodies of medium-grained, non-porphyritic adamellite are also present in the New Ross-Vaughn pluton. One, a pinkish-grey variety, occurs north of Chester Basin, Lunenburg Co. near the intrusive/meta-sediment contact. The second, buff-grey in colour, is located south of Walden, Lunenburg Co. and may also be in contact with the country rocks (Fig. 4.2). Although extensive sericitization and hematization of plagioclase has inhibited composition determinations, it would appear that maximum anorthite contents are in the oligoclase/andesine range. Again, the rims of larger grains and some small unzoned grains have albitic compositions. The remaining mineralogy is also characteristic of adamellites.

In two areas along the northern boundary of the New Ross-Vaughn complex, a unique contact facies adamellite has been observed intruding the Meguma inlier (Fig. 4.2). The phase is reddish-brown in colour and medium-grained, hypidiomorphic granular in texture. Alkali feldspar phenocrysts comprise 1% to 3% of the rock and attain a maximum size of 2 cm.

Plagioclase appears to be andesine (An_{36}) in composition, but since the optical properties are obscured by the very extensive reddening and sericitization of this mineral, albitic compositions are a possibility. The biotite is almost all altered to chlorite with small amounts of epidote. The alkali feldspar is not as altered as the plagioclase, but still shows considerable reddening. Exsolution stringers, small inclusions and some microcline grid-twinning are other salient features. The remaining essential minerals, quartz and muscovite, were unaffected by the alteration.

Apatite is the principal accessory mineral in this phase. Zircons are present in unaltered biotite, but andalusite has not been noted.

Xenoliths are absent from this rock in spite of the fact that it is in contact with the metasediments. The implications of the lack of xenoliths to the mode of emplacement of this lithology and the emplacement of the adamellite pods in general is dealt with in Chapter 6.

VIII Chemistry

The major and trace element chemistry of the adamellites, in addition to the normative and modal compositions, are given in Tables 4.2 and 4.3. Silica values range from 71.1% to 75.2% and are usually higher than those of the biotite granodiorites. Potash levels are also generally higher whereas TiO_2, Fe_{Total}, MnO, MgO and CaO levels are lower than those of the granodiorites. Alumina, Na_2O, P_2O_5 and H_2O^+ are not significantly different between the two rock types.

Trace element data supports the major element trends. The adamellites are enriched in Rb relative to the granodiorites and are relatively depleted in Zr, Sr and Ba. Zinc, which is fractionated by biotite (Wedepohl, 1972) is also less abundant in the adamellites.

As with the biotite granodiorites, all adamellites have corundum in the CIPW norm. In addition, the normative differentiation index ranges from 86.8 to 92.7 while the colour index varies from 6.0 to 3.3.

IX Summary

Adamellitic rocks within the South Mountain batholith occur in four large, irregularly shaped pods. Except for the Lake George body, the pods are made up of a number of different textural types, which are distinguished by such parameters as grain size and phenocryst abundance. The West Dalhousie and Springfield Lake plutons are essentially two-phase pods whereas the New Ross-Vaughn complex includes five to seven texturally diverse phases.

The various adamellites are mineralogically and chemically rather similar. They are characterized by the presence of two micas and roughly equal modal proportions of plagioclase and alkali feldspar. They are more acid than the biotite granodiorites and accordingly have higher SiO_2 and K_2O levels with lower TiO_2, Fe_{Total}, MgO and CaO abundances.

Table 4.1

Adamellite plutons of the South Mountain batholith

Name	Size (km^2)	Textural types	Plagioclase Compositions	Alkali feldspar Phenocryst Abundance	Differentiation Index	Comments
West Dalhousie	300	1. porphyritic 2. non-porphyritic 3. minor intrusives (Chapter 5)	oligoclase/andesine	15%-25%	88.2	colour: light grey hydrothermal alteration: minor andalusite: rare
Springfield Lake	150	1. porphyritic 2. non-porphyritic 3. minor intrusives (Chapter 5)	oligoclase/andesine	15%-25% <3%	92.2	colour: light grey, buff and pinkish hydrothermal alteration: common and locally extensive andalusite: apparently rare
Lake George	120	1. porphyritic	oligoclase/andesine	10%-30%	91.5	colour: buff and pinkish grey hydrothermal alteration: common, rock sometimes friable, andalusite: common.
New Ross-Vaughn	500	1. porphyritic a. phenocryst-poor b. phenocryst-rich	oligoclase/andesine and albite	15%-25% 1%-5% 30%-40%	91.4	miarolitic cavities
		2. medium-grained, subporphyritic	oligoclase/andesine	>3%	89.4	colour: light grey, buff, pinkish and reddish; extensive hydrothermal alteration: common, locally very extensive andalusite: common miarolitic cavities fluorite. Sn, W, Mo mineralization
		3. coarse-grained, subporphyritic, "fresh"	oligoclase/andesine	>3%	91.4	
		4. medium-grained	oligoclase/andesine	-		
		5. contact facies	oligoclase/andesine	>3%		
		6. minor intrusives (Chapter 5)				

Table 4.2

Modal Analyses (in volume per cent) of chemically analyzed adamellites

	West Dalhousie		Springfield Lake	Lake George	New Ross - Vaughn					
Sample No.	M72-50	82	189	102	114	119	121	161	166	176
Quartz	34.2 (37.6)	25.4 (28.6)	28.6 (30.9)	37.8 (41.7)	33.8 (36.4)	44.8 (48.0)	32.3 (34.0)	32.1 (35.4)	31.6 (35 [illegible])	32.1 (33.5)
Plagioclase	23.5 (25.4)	24.8 (27.9)	23.4 (25.3)	22.1 (24.4)	20.6 (22.2)	25.4 (27.2)	26.4 (27.8)	26.3 (29.1)	26.0 (28.6)	29.2 (30.2)
K-Feldspar	34.8 (37.6)	38.6 (43.7)	40.4 (43.7)	30.6 (33.8)	38.4 (41.3)	23.1 (24.8)	36.2 (38.1)	32.0 (35.4)	33.1 (36 [illegible])	35.3 (36.0)
Biotite	6.6	10.5	2.6	8.9	5.6	3.4	3.7	5.6	6.4	4.4
Muscovite	.9	.7	5.0	.7	1.5	3.0	1.4	3.8	.7	1.1
Accessories	-	-	-	-	-	-	-	.6	-	-

Table 4.3

Chemical analyses of adamellites

	West Dalhousie		Springfield Lake	Lake George	New Ross-Vaughn					
Sample No.	M72-50	82	189	102	114	119	121	161	166	176
Major elements (%)										
SiO_2	73.2	71.1	75.2	73.7	74.5	74.3	73.5	72.4	74.3	72.0
TiO_2	.29	.42	.17	.26	.12	.22	.18	.29	.14	.32
Al_2O_3	13.93	14.50	13.71	13.42	13.40	13.08	13.87	14.10	13.58	13.86
Fe_2O_3	.20	.29	.08	.17	.16	.05	.22	.18	.12	.08
FeO	1.80	2.13	1.40	1.69	1.51	1.77	1.55	1.87	1.22	2.16
MnO	.04	.06	.04	.04	.05	.05	.03	.05	.06	.06
CaO	.80	1.10	.51	.58	.45	.66	.60	.71	.52	.78
Na_2O	3.24	3.30	3.32	3.32	3.46	3.60	3.54	3.23	3.29	3.36
K_2O	5.12	4.90	4.76	4.91	4.59	4.34	4.72	4.83	4.90	4.43
H_2O^+	.96	.66	.67	.82	.58	.77	.69	.74	.65	1.05
P_2O_5	.04	.08	.16	.07	.14	.07	.15	.10	.06	.31
Total	100.11	99.17	100.29	99.26	99.08	99.16	99.29	99.00	99.02	98.95
Trace elements (ppm)										
Sn	10	7	20	19	30	15	20	15	10	18
Rb	272	221	362	330	532	299	441	324	295	264
Sr	47	40	-	-	-	-	-	2	-	22
Ba	418	491	193	230	66	200	164	341	124	312
Zr	118	125	44	91	51	76	64	118	40	125
Zn	62	70	52	72	64	56	64	62	38	60
Ni	12	14	8	8	8	10	9	11	8	12
Cr	42	44	28	43	45	47	47	40	35	41

Table 4.4

CIPW Norms of chemically analyzed adamellites

	West Dalhousie		Springfield Lake	Lake George	New Ross-Vaughn					
Sample No.	M72-50	82	189	102	114	119	121	161	166	176
Quartz	31.43	29.09	35.70	33.45	35.42	34.37	32.96	32.37	34.83	32.99
Orthoclase	30.54	29.42	28.26	29.50	27.56	26.09	28.32	29.08	29.46	26.76
Albite	27.64	28.34	28.20	28.53	29.72	30.96	30.38	27.81	28.30	29.04
Anorthite	3.74	5.01	1.49	2.46	1.34	2.86	2.20	2.92	2.22	1.88
Hypersthene	3.99	4.73	2.98	3.36	2.88	3.59	3.06	4.22	2.51	4.93
Magnetite	.29	.43	.12	.25	.24	.07	.32	.27	.18	.12
Ilmenite	.56	.81	.32	.50	.23	.43	.35	.56	.27	.62
Apatite	.09	.19	.37	.17	.33	.17	.35	.24	.14	.73
Corundum	1.71	1.98	2.56	1.78	2.29	1.46	2.23	2.55	2.09	2.92
Differention Index	89.6	86.8	92.2	91.5	92.7	91.4	91.6	89.2	92.6	88.8
Colour Index (wt. pct.)	4.8	6.0	3.4	4.1	3.3	4.1	3.7	5.0	3.0	5.7

CHAPTER 5: DYKE ROCKS AND MINOR INTRUSIVE BODIES

I Introduction

Aplite, pegmatite and porphyry dykes and other minor intrusive bodies are found throughout the South Mountain batholith, cutting both the biotite granodiorites and the adamellites. Map 1 and Figures 1.1, 4.1 and 4.2 give the locations of the larger intrusions of this type, as well as the positions of smaller, analyzed dykes. These rocks, although geographically widespread, constitute the least voluminous phases of the batholith.

For the most part, the dykes are in sharp intrusive contact with the earlier granitic phases and, as suggested in Chapter 2, may be related to primary igneous jointing. On the other hand, the small intrusive bodies often have irregular contacts and thus their relations to pre-existing structures are not always apparent.

Mineralogically, the dyke rocks and minor intrusives fall roughly into three groups. Aplites and all but one of the small bodies (i.e. the Morse Road body) are characterized by quartz, potassic feldspar, albitic plagioclase, biotite and muscovite. The aplites, however, are usually alaskitic (An_{0-5}) whereas some of the minor intrusive bodies are leucoadamellitic (An_{5-10}) in composition. Pegmatites are typified by quartz, potassic feldspar, muscovite and biotite. Tourmaline is also common and is usually found in dyke cores. The porphyries are similar to the aplites, except that most have plagioclase phenocrysts of oligoclase/ andesine composition.

On the whole, the dyke rocks and minor intrusive bodies are the most silicic and highly differentiated rocks of the batholith. Silica, alkali and Rb concentrations are high whereas Ca, Mg, Fe_{Total}, Ba, Zr, Sr levels are very low. Thus the chemistry as well as the field relations and petrography indicate that the small-scale intrusives represent a late magmatic stage in the development of the pluton.

II Definition

The principal difference between the dyke rocks and the minor intrusive bodies lies in their respective sizes. The aplites, pegmatites and porphyries generally occur as tabular, cross-cutting dykes which seldom attain thicknesses of more than a few meters. The minor intrusives, though often texturally and compositionally similar to the dyke lithologies, form irregular bodies several square kilometers in area. More detailed mapping may show that a complete size gradation exists between the two phases, but at present this means of classification seems applicable.

III The Dyke Rocks

1. Aplites

Aplite dykes occur throughout the South Mountain batholith, intruding both the biotite granodiorites and the two-mica adamellites. Contacts with the host rocks are sharp yet seldom show chilled margins. The dykes appear to follow the igneous jointing pattern (Chapter 2) and, indeed, dyke injection may have been initiated by fracturing due to cooling.

Aplites occurring within the granodiorites are generally small, continuous dykes which average 5 to 15 cm in width. Only rarely do they attain a thickness of a few meters. In addition, the dykes do not appear to have any preferential distribution within the granodiorite and are as common in the centre of the batholith as they are at the margins. In the adamellite pods large dykes, up to several meters thick, are common. As noted before, it is possible that there is a complete size gradation from the large dykes to the small intrusive bodies.

The aplites are whitish- to pinkish-grey rocks that characteristically have fine- to medium-grained, equigranular, saccharoidal textures. Larger dykes may develop occasional phenocrysts and slightly coarser grain sizes, but still retain the "aplitic" aspect. Quartz, potassic feldspar, albitic plagioclase, muscovite and biotite constitute the essential minerals. Aplite modes are given in Table 5.2.

Quartz is usually anhedral and fine- to medium-grained; however, in larger dykes rare grains or grain aggregates .5 to 2 cm in diameter may be developed. Muscovite is the most common mineral poikilitically included in quartz, but plagioclase, biotite and potassic feldspar may also occur as inclusions.

Plagioclase is generally unzoned and albitic in composition. Small, spherical quartz grains are the most abundant inclusions. Sericite alteration and hematite reddening are ubiquitous. The potassic feldspar may be microperthitic and commonly displays microcline grid-twinning. Quartz is the most frequent included mineral; plagioclase and the micas occur less often. Kaolinite, muscovite and reddening by hematite dust are the principal types of alteration.

Biotite is not common in the aplites and is usually altered to chlorite ($\pm$ epidote) or muscovite. Zircon and apatite inclusions appear to be rare although their presence may be obscured by the alteration. Muscovite is the dominant mica and occurs both as a primary and secondary mineral. The primary muscovite occasionally encloses small andalusite grains.

Accessory minerals are represented by a wide range of mineral species. Apatite, zircon, andalusite, tourmaline, fluorite, garnet and topaz have been observed in the aplites. No one aplite, however, will contain all six minerals. For example, topaz, which is retricted to dykes of the New Ross-Vaughn complex, has not been seen co-existing with the chemically similar andalusite.

Metasedimentary xenoliths are entirely absent from the aplites.

2. Pegmatites

Pegmatitic material occurs in continuous pegmatite dykes, in the cores of aplites and as relatively small, discontinuous segregations in the granodiorites and adamellites. The pegmatite dykes are generally found associated with aplites and have similar attitudes. They are small, ranging from a few centimetres to perhaps a meter in width, and have sharp contact relations with the host rock. The mineralogy is generally simple; the common assemblage being quartz, alkali feldspar (occasionally with graphic intergrowths), muscovite and biotite. Tourmaline is the only common accessory mineral and it usually occurs in the core of the dyke. Larger pegmatites with complex mineralogy are present within the New Ross-Vaughn pluton; however, because of their economic importance they are discussed in Chapter 8.

There are two types of pegmatitic segregations in the batholith. One variety exists as small, discontinuous pods which rarely exceed a meter in the long direction. The mineralogy is similar to that of the dykes and contacts with the granitic host (which may be granodiorite, adamellite or a minor intrusive body) are sharp.

The second type of segregation can best be described as clusters of alkali feldspar phenocrysts. The clusters are comprised of at least 90% perthitic potassic feldspar with quartz, biotite and/or muscovite constituting the remainder. Contacts with the host rocks are gradational. Occasionally xenoliths are associated with such clusters in the biotite granodiorites. These characteristics and the transection of one of the aggregations by a pegmatite dyke suggest that this sort of segregation is a cognate accumulation of phenocrysts and unrelated to the late-stage, intrusive pegmatites.

3. Porphyries

The porphyries are also widespread in the South Mountain batholith and occur as dykes or dyke-sized irregular bodies which are generally much larger than the average aplite or pegmatite. Most would seem to have sizes ranging from several tens to a few hundred meters in width. Contacts between the porphyries and the host granitic rocks are sharp, but unlike those of the other dyke rocks, often irregular. Thus, they do not seem to have been as directly controlled by the igneous fracture pattern.

Porphyry lithologies may be light grey, buff, pinkish or reddish in colour. They have a distinctive bimodal grain size distribution. The groundmass is fine- to medium-grained and aplitic in aspect. The porphyritic minerals are generally coarse-grained and have the appearance of floating in the groundmass. Potassic feldspar and quartz are the most common phenocrysts, attaining maximum modal proportions of 5% and 2%, respectively. Porphyritic plagioclase and biotite are also present, but occur less frequently.

Quartz is found both as a groundmass and porphyritic mineral in the porphyries. The phenocrysts are anhedral, roughly spherical and vary from .4 to 2 cm in diameter. Plagioclase, potassic feldspar, muscovite and biotite have all been observed as inclusions. In addition, the edges of the phenocrysts often have a "corroded" appearance. Probably this feature resulted from chemical disequilibriums between the phenocrysts and the liquid magma.

Plagioclase is also represented in both size modes. Porphyritic plagioclase has oscillatory, normal and patchy zoning as well as normally zoned, clear sodic rims. Small, spherical quartz inclusions are common within the rims and are often concentrically arranged. Myrmekitic intergrowths are also characteristic of the grain margins. Sericite alteration and reddening by hematite dust (when present) are concentrated in the grain cores. Maximum anorthite contents determined from the cores are in the oligoclase/andesine range.

Plagioclase in the groundmass may exhibit oscillatory zoning, normal zoning or be unzoned. Generally speaking, the plagioclase is compositionally the same as the phenocrysts in porphyries that cut the biotite granodiorites; whereas the compositions are albitic in porphyries intruding the adamellites. Sample M72-198, a porphyry from the Morse Road adamellite, is a notable exception to this generalization.

The alkali feldspar phenocrysts (Or_{95}) range in size from 1 to 6 cm and have an average length of 2 to 3 cm. Commonly, they are euhedral, lath-shaped crystals with random orientations. Plagioclase, quartz and mica inclusions are common and are often zonally arranged around the margins of the grains. The phenocrysts are perthitic and may show microcline grid-twinning. Groundmass potassic feldspar may be microperthitic and often has grid-twinning. Micrographic quartz intergrowths are also relatively abundant. The normal types of alkali feldspar alteration are common to both sizes.

Biotite and muscovite are primarily groundmass minerals. Usually biotite is partially altered to chlorite with lesser amounts of epidote and muscovite. Unaltered grains display zircon inclusions with pleochroic haloes and apatite inclusions; opaque minerals are almost always absent. The rare biotite phenocrysts are essentially similar to the groundmass grains. Primary muscovite is present in all the porphyries and it often contains quartz inclusions. Zircon and apatite are by far the most abundant accessory minerals; however, minor tourmaline and opaque minerals have also been observed. Unlike the aplites, andalusite is very rarely found in the porphyries.

Temporal relations among the dyke rocks are generally not well known. In one instance, however, where a porphyry has been observed in contact with biotite granodiorite, the porphyry itself has been cut by an aplite. This, combined with the mineralogical differences between the porphyries and the other dyke rocks, implies that at least some of the porphyries pre-date the aplite and pegmatite dyke activity.

IV Minor Intrusive Bodies

General Petrography

Minor intrusive bodies are found emplaced into the biotite granodiorites and associated with three of the four adamellitic plutons (i.e. West Dalhousie, Springfield Lake and New Ross-Vaughn). The bodies occur as cupolas or very large, tabular dykes which are of sufficient size to form mappable units (Figs. 1.1, 4.1, 4.2). The rocks of these intrusions, although in many cases mineralogically, chemically and even texturally similar to the dyke rocks, are referred to as alaskites and albitic leucoadamellites so that they will not be confused with the much less extensive aplite, pegmatite and porphyry dykes.

In total, eight such bodies have been recognized and mapped to some extent. They are as follows:

1. Greywood leucoadamellite
2. Morse Road adamellite
3. Inglisville alaskite
4. Murphy Lake alaskite
5. Lake Ramsay alaskite
6. Leminster alaskite
7. Lewis Lake leucoadamellite
8. Card Lake alaskite

Similar rocks from the Springfield Lake pluton have not been enumerated here, as the present mapping and sampling have been insufficient to adequately characterize them. Table 5.1 summarizes the data currently available for the minor intrusive bodies listed above.

1. Greywood Leucoadamellite

Intruded along the northwest side of the West Dalhousie adamellite and just to the south of the main pod, are two bodies of albitic leucoadamellite (Fig. 4.1). They apparently post-date the adamellites as well as the biotite granodiorite, although no contacts were observed in the field. The rocks in both bodies grade from a pink aplite near their southerly contacts into whitish-grey aplite and then into a pink or whitish-grey, medium-grained rock which has occasional potassic feldspar phenocrysts (Or_{94}), .5 to 2 cm in length. The bodies are not bilaterally symmetrical, however, since the medium-grained phase appears to extend to the northern limits of both intrusions.

The medium-grained phase is comprised of quartz, plagioclase, potassic feldspar, biotite, muscovite and accessory minerals. The plagioclase is albitic and gives a compositional range from An_6 to An_{10}. Zoning is minor and restricted to the normal type. Sericite alteration and reddening by hematite dust are generally extensive. Alkali feldspar typically occurs as groundmass-sized, oriented laths which occasionally grade into phenocrysts. Grid-twinning, inclusions of plagioclase, quartz and mica and occasional perthitic textures are all features of the potassic feldspar. Kaolinite and muscovite may be secondary after this feldspar and, like the plagioclase, grains may be faintly reddened by occluded hematite dust.

Biotite and muscovite in the medium-grained leuco-adamellites are in roughly equal proportions. The biotites are often altered to chlorite and opidote, and to a lesser extent, muscovite. Where the biotite remains unaffected, however, inclusions of zircons with pleochroic haloes, apatites and opaque minerals occur. Muscovite is present both as a primary and secondary mineral. The primary variety occasionally mantles andalusite.

The accessory minerals (apatite, zircon, andalusite and opaques) generally occur in association with the micas. Metasedimentary xenoliths are not found in the Greywood leucoadamellite lithologies.

2. Morse Road Adamellite

A small porphyritic adamellite body has been mapped along the Morse Road, south of Bridgetown, Annapolis Co. (Fig. 1.1). The body is approximately 2.5 km across and not more than 15 km in length. The rock is light grey to pinkish grey in colour and in general petrographically similar to the porphyritic adamellites of the West Dalhousie pluton. However, in the south part of the body the typical porphyritic lithology grades into a peculiar phase that has not been noted elsewhere in the batholith. This unique adamellite is characterized by numerous, small, delicate alkali feldspar phenocrysts. The crystals are lath-shaped, aligned NE-SW and have average dimensions of 1 cm by .2 cm. The intrusion is also cut by an adamellitic porphyry (Sample M72-198) which is 0.25 km wide.

3. Inglisville Alaskite

Alaskitic rocks occupy two small embayments in the metasediments near Inglisville, Annapolis Co. (Fig. 1.1). These bodies consist of pink aplites and medium-grained, non-porphyritic alaskites. In the southerly body, aplite appears near the contact with the biotite granodiorites and grades into the medium-grained variety. Aplite in the second intrusion, however, apparently cross-cuts the coarser-grained lithology.

The medium-grained alaskites are pinkish- to flesh-coloured and hypidiomorphic-granular in texture. They contain quartz, potassic feldspar, plagioclase, muscovite and biotite. The potassic feldspar is perthitic and commonly displays microcline grid-twinning. Plagioclase, quartz and mica inclusions are present but not abundant. Plagioclase is albitic (An_4) and is occasionally normally zoned. Both feldspars are somewhat altered and tinted by occluded hematite dust. Biotite has been partially or completely altered to chlorite, hematite and/or muscovite. Neither accessory minerals nor metasedimentary xenoliths have been noted in this rock.

From the gradational relations shown between aplites and medium-grained phases of the Greywood and Inglisville minor intrusive bodies, it appears that the texture of the late-stage rocks is dependent on the size of the intrusion. Small intrusions (i.e. dykes), whether they undergo pressure or thermal quenching, crystallize very rapidly and thus have aplitic textures. However, the larger alaskite intrusions, while often aplitic (chilled) along the margins, cool and crystallize more slowly because of their increased size. Accordingly, coarser grain sizes and a few phenocrysts are able to develop away from the contacts. This phenomenon is demonstrated to a lesser extent by large aplite dykes which are usually slightly coarser-grained than aplitic veins.

4. Murphy Lake Alaskite

Just to the south of Gaspereau Lake, Kings Co., a small alaskitic body has been emplaced into the biotite granodiorites (Fig. 1.1). The intrusion consists of three textural phases which appear to be gradational into one another. An alaskitic porphyry is the dominant phase while aplite and pegmatite constitute the remainder of the body. Most of the rocks are pinkish- or reddish-grey; however, along the north side of the intrusion the porphyry is buff-coloured.

Mineralogically, the porphyry and aplite are comprised of quartz, albitic plagioclase, potassic feldspar, muscovite, biotite and minor amounts of zircon and apatite. The pegmatite is composed primarily of quartz, potassic feldspar and muscovite. The potassic feldspars may contain graphic quartz intergrowths and attain 20 cm in their maximum dimension.

To the south of the intrusion, near Murphy Lake, a large pink aplite dyke (?) has been mapped by Faribault, Armstrong and Wilson (1939) as continuous with the alaskite. Recent mapping has not been able to confirm this relationship.

5. Lake Ramsay Alaskite

There are at least four minor intrusive bodies in the New Ross-Vaughn complex (Fig. 4.2). Two of these consist essentially of aplitic and porphyry lithologies which are comparable to similar rocks elsewhere in the batholith.

The first occurs in a dyke-like body approximately 1.2 km wide, near Lake Ramsay, Lunenburg Co. It forms the western boundary of the New Ross-Vaughn pluton. Indeed, the contact between this minor intrusive and the biotite granodiorites has been exposed in drill core.[1] The biotite granodiorites are cut by a pink-coloured porphyry with an apparent thickness of 6 m. The actual contact is sharp but the granodiorites have been intruded by thin aplite apophyses and extensively altered up to 2.5 m away from the intrusive boundary. The porphyry is also in contact with aplitic alaskite. The intrusive relations between these phases, however, are not clearly defined in the drill core.

Porphyry and medium-grained, aplitic alaskite have also been observed in the field, but insufficient exposure exists to characterize either the spatial distribution or the intrusive relations of the two phases. It is also noteworthy that the medium-grained alaskite is the host for two, perhaps three, mineralized pegmatites. These occurrences are discussed in more detail in Chapter 9.

6. Leminster Alaskite

A second large body of aplite and porphyry lithologies is found in the northeast of the New Ross-Vaughn complex (Fig. 4.2). Again, as exposure is poor, it is difficult to know whether the rocks form a continuous body or if, in fact,

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[1]Hole NR37; drilled by N.S. Dept. of Mines as part of the New Ross Project, 1963.

they represent a series of large, closely spaced dykes. In addition, no contacts with either the New Ross-Vaughn adamellites or the Meguma inlier have been observed. A further complication is that much of this body lies within the zone of intense reddening and alteration. This fact has often made the identification of phases in the field nearly impossible.

7. Lewis Lake Leucoadamellite

Minor intrusions of a different nature outcrop in the Lewis Lake and Card Lake areas of Lunenburg Co. Near Lewis Lake an albitic (An_{6-8}) leucoadamellite body intrudes the porphyritic adamellites. From east to west, the leucoadamellites apparently grade from a light grey, medium-grained, non-porphyritic phase into a buff-coloured, medium- to coarse-grained, subporphyritic lithology. The medium-grained rock is chilled against the adamellites giving it an aplitic aspect within a few meters of the contact. Right at the contact fragments of the adamellite have been taken up by the aplitic phase.

The coarse-grained, subporphyritic leucoadamellite is difficult to distinguish from the albitized, subporphyritic adamellites of the New Ross-Vaughn complex (Chapter 4). However, it is considered part of the minor intrusion for two reasons. First, it is not as altered as the albitized adamellites. In the second place, both this phase and the medium-grained leucoadamellite contain topaz rather than andalusite as an accessory mineral.

8. Card Lake Alaskite

North of Card Lake, Lunenburg Co., on the eastern side of the thesis area, a body of pink alaskite has invaded the medium-grained, subporphyritic adamellites. The alaskite is generally medium-grained (.1 to .3 cm) and aplitic in texture. In addition, clumps of biotite and/or muscovite and/or quartz, .4 to 1 cm in diameter, comprise 1% to 2% of the rock and give it a spotted appearance. The mineral assemblage is quartz, albitic plagioclase (An_5), potassic feldspar, muscovite and biotite. The plagioclase is unzoned and is the predominant feldspar. Both feldspars are reddened by occluded hematite dust; however, the potassic feldspar is the more altered of the two. Biotite is almost always chloritized or muscovitized. Apatite and zircon are the only accessory minerals that have been noted.

Pegmatite segregations, also common in the alaskite, range from a few 10's of cm to a few meters in size. Moreover, pink granophyric pegmatites are often interspersed with the aplitic alaskite along the contacts. The alaskite/adamellite contacts are sharp but irregular and lacking in any definite orientation. Occasionally the alaskite shows a thin (2 cm) chilled margin and in one area large xenoliths of adamellite characterize the contact zone. From these contact relations, it seems that this body (and the Lewis Lake leucoadamellite) was intruded after the enclosing adamellites had solidified and cooled considerably.

V Chemistry

The dyke rocks and minor intrusive bodies are among the most silicic members of the South Mountain batholith (Table 5.3). SiO_2 values range from 72.4% to 76.3% and total alkalies vary from approximately 7.5% to 8.5%. Not unexpectedly, oxides such as TiO_2, Fe_{Total}, MnO, MgO and CaO are less abundant in these rocks than in the granodiorites or adamellites. The CIPW norms (Table 5.4) also reflect the highly fractionated nature of the small-scale intrusives. The normative differentiation and colour indices average 92.8 and 2.8, respectively.

The trace element data shows that these phases are typified by high Rb levels and low Sr, Zr and Ba levels. The data also indicates that there may be subtle chemical differences between the minor intrusions of the various adamellite plutons. Aplites, porphyries and related rocks from the western end of the batholith (i.e. the West Dalhousie adamellite and the Morse Road adamellite) have much lower Rb levels than similar phases from the Lake George and New Ross-Vaughn pods. Strontium, zirconium and barium generally show the reverse relations, although there are certain discrepancies. The possibility of chemically distinguishing the adamellite plutons is considered further in Chapters 6 and 8.

VI Summary

Late-stage, highly differentiated rocks occur in the South Mountain batholith in one of two ways. First, there are numerous aplite, pegmatite and porphyry dykes and apophyses intruded throughout the pluton. The dykes have a bimodal size distribution with the aplites and pegmatites typically being smaller in size than the porphyries. Indeed, the textural differences between the aplites and porphyries may be a function of their respective sizes.

The second principal mode of occurrence is in small alaskite and albitic leucoadamellite bodies. Often these bodies are merely associations of aplitic, pegmatitic and porphyry lithologies which together constitute sizeable intrusions. However, the alaskites and leucoadamellites also include medium-grained, non-porphyritic to subporphyritic rocks that are easily distinguishable from the dyke rocks.

There is both mineralogical and chemical evidence that these phases represent the final magmatic stages of the batholith. Plagioclase is for the most part albitic, mafic minerals (e.g. biotite) are scarce and volatile-rich accessories such as tourmaline, fluorite and topaz may be present. Moreover, SiO_2, the alkali oxides and Rb are abundant whereas the cafemic oxides, Zr, Sr and Ba are relatively depleted in these rocks.

Table 5.1

Minor intrusive bodies of the South Mountain batholith

Name	Host	Textural Types	Plag. Comp.	Phenocrysts Type/Abundance	Comments
Greywood	West Dalhousie adamellite, biotite granodiorite	1. medium-grained subporphyritic 2. aplitic	An_{6-10}	1. K-feldspar/<1%	colour: whitish-grey of pinkish-grey alteration: moderate accessory andalusite
Morse Road	biotite granodiorite	1. porphyritic 2. porphyry	An_{33}	1. K-feldspar/25% 2. K-feldspar/<5% quartz/<1% biotite/minor	colour: light grey, alteration: weak, porphyry contains tourmaline
Inglisville	biotite granodiorite and metasediments	1. medium-grained non-porphyritic 2. aplitic	An_4	-	colour: pinkish-grey, alteration: moderate
Murphy Lake	biotite granodiorite	1. porphyry 2. aplitic 3. pegmatitic	An_4	1. K-feldspar/<1% quartz/<1% plagioclase, biotite minor	colour: pinkish-and buff-grey
Lake Ramsay	biotite granodiorite and New Ross-Vaughn complex	1. porphyry 2. medium-grained non-porphyritic 3. pegmatitic	An_5	1. quartz/1% plagioclase, biotite minor	colour: whitish-grey, buff-grey, alteration: moderate to strong mineralized pegmatites
Leminster	New Ross-Vaughn complex and metasediments	1. porphyry 2. aplitic	An_5	1. K-feldspar/<5% quartz/<2% plagioclase, biotite minor	colour: reddish-grey, alteration: very strong
Lewis Lake	New Ross-Vaughn complex	1. medium-grained subporphyritic 2. medium-grained non-porphyritic	An_{6-8}	1. K-feldspar	colour: whitish-and buff-grey, alteration: moderate, accessory topaz
Card Lake	New Ross-Vaughn complex	1. aplitic 2. pegmatitic	An_5	1. quartz & mica eyes/1%	colour: pinkish-grey, alteration: moderate

Table 5.2

Modal analyses (in volume per cent) of chemically analyzed dyke rocks and minor intrusive bodies

	Greywood		Aplite	Morse Road	Aplite	
Sample No.	M72-43B	52	182	198	100A	116A
Quartz	32.3 36.7	31.1 33.7	33.7 36.8	30.3 33	34.1 36.8	33.6 35.4
Plagioclase (Albite)	28.4 32.1	24.6 26.6	20.4 23.8	33.0 35.9 (An_{32})	46.6 50.3	38.1 40.1
K-Feldspar	27.6 31.2	36.6 39.6	31.3 39.4	28.4 30.9	11.8 12.7	23.3 24.5
Biotite	3.0	4.2	1.8	4.5	2.2	-
Muscovite	8.1	3.5	12.4	3.6	5.3	4.6
Accessories	.6	.1	.4	.2	-	.2

	Porphyry	Card Lake	Porphyry	Lewis Lake
Sample No.	123	156	160	197
Quartz	40.2 35.5	32.7 34.5	40.6 44.6	34.2 40.4
Plagioclase	24.5 27.0	38.8 40.9	21.2 23.3	38.5 45.5
K-Feldspar	25.9 28.5	23.3 24.5	29.2 32.1	11.8 13.9
Biotite	1.0	3.0	5.0	.6
Muscovite	8.4	2.0	3.6	12.7
Accessories	-	.1	.2	2.0

Table 5.3

Chemical analyses of dyke rocks and minor intrusive bodies

	Greywood		Aplite	Morse Road	Aplite		Porphyry	Card Lake	Porphyry	Lewis Lake
Sample No.	M72-43B	52	182	198	100A	116A	123	156	160	197
Major elements (%)										
SiO_2	73.6	75.1	76.3	74.0	75.0	74.1	74.0	76.0	73.3	72.4
TiO_2	.17	.24	.06	.30	.09	.09	.18	.05	.22	.06
Al_2O_3	14.00	13.45	13.87	13.50	14.20	14.07	13.20	13.05	13.53	14.25
Fe_2O_3	.27	.51	.09	.22	.58	.23	.17	.06	.19	.22
FeO	.98	1.27	.75	1.86	.62	.82	1.09	.93	1.66	1.01
MnO	.04	.04	.04	.07	.03	.03	.03	.04	.06	.03
MgO	.27	.36	.11	.50	.08	.10	.08	.08	.23	.10
CaO	.54	.49	.45	.91	.53	.44	.43	.34	.63	.48
Na_2O	3.44	3.10	3.62	3.07	4.57	3.84	4.00	3.76	3.19	3.25
K_2O	5.02	5.28	4.45	4.58	3.60	4.37	4.31	4.62	4.69	4.37
H_2O^+	.82	.90	.71	.71	1.01	.79	.68	.70	.72	.79
P_2O_5	.14	.05	.05	.05	.28	.14	.21	.17	.16	.36
Total	99.20	100.79	100.50	99.77	100.59	99.02	98.26	100.25	98.50	97.32
Trace elements (ppm)										
Sn	15	10	20	12	22	40	25	30	18	50
Rb	268	253	294	202	402	660	620	590	410	816
Sr	26	35	-	46	-	-	-	-	-	-
Ba	301	402	44	339	8	16	28	12	141	24
Zr	55	100	-	94	-	-	20	-	78	-
Zn	44	47	34	49	33	43	64	37	69	80
Ni	6	8	8	11	9	9	9	9	9	10
Cr	32	44	34	50	42	37	38	36	38	46

Table 5.4

CIPW Norms of chemically analyzed dyke rocks and minor intrusive bodies

	Greywood		Aplite	Morse Road	Aplite		Porphyry	Card Lake	Porphyry	Lewis Lake
Sample No.	M72-43B	52	182	198	100A	116A	123	156	160	197
Quartz	33.08	34.71	36.70	35.07	34.05	34.38	33.76	35.47	35.09	37.14
Orthoclase	30.15	31.26	26.38	27.35	21.38	26.31	26.13	27.45	28.35	26.78
Albite	29.56	26.26	30.69	26.22	38.83	33.08	34.68	31.96	27.58	28.49
Anorthite	1.79	2.11	1.91	4.23	.80	1.29	.78	.58	2.12	.03
Hypersthene	2.07	2.49	1.55	4.15	.77	1.50	2.07	1.86	3.28	1.95
Magnetite	.40	.74	.13	.32	.84	.34	.25	.09	.28	.33
Ilmenite	.33	.46	.11	.57	.17	.17	.12	.10	.43	.12
Apatite	.33	.12	.12	.12	.65	.33	.50	.40	.38	.86
Corundum	2.29	1.86	2.40	1.97	2.50	2.60	1.71	2.11	2.49	4.31
Differentiation Index	92.8	92.2	93.8	88.6	94.3	93.8	94.6	94.9	91.0	92.4
Colour Index (wt pct)	2.8	3.7	1.8	5.0	1.8	2.0	2.4	2.0	4.0	2.4

CHAPTER 6: PETROGENESIS

I Introduction

The South Mountain batholith consists of a consanguineous suite of granodiorites, adamellites, dyke rocks and minor intrusives. The variability of the body is attributable to a process of fractional crystallization. The original magma was transitional between granodioritic and adamellitic compositions and may have been somewhat basified by the assimilation of country rock during the initial stages of emplacement. With ensuing crystallization five adamellite bodies were evolved from the granodiorites. Magmatism concluded with the intrusion of a series of dyke rocks and minor intrusive bodies.

The magma ascended into high crustal levels through a conduit centred about New Ross, Lunenburg Co. Initially, the magma moved upwards by a mechanism of plastic deformation in the lower crust. However, as the melt spread out and reached its maximum level of ascent, stoping became the principal mode of emplacement. Field and petrologic data from the various granitic phases suggest that depths to the upper levels of the batholith did not exceed 15 km.

Determining the parentage of the South Mountain batholith, and for that matter orogenic batholiths in general, is still a matter of some conjecture. The overall composition of the pluton is somewhat more silicic than the Meguma country rocks and thus partial melting of these (or similar) metasediments might produce abundant magma of the proper composition. In addition, the peraluminous character of the batholith suggests that pelitic sediments had an important role in its origin. On the other hand, the Sr^{87}/Sr^{86} ratios lie in a range lower than that expected for crustally derived rocks. However, as this is presently the only line of evidence suggestive of a mantle source, the South Mountain batholith is discussed in terms of deep crustal origins.

II Chemical Relations

Harker variation diagrams for the South Mountain batholith rocks are shown in Figure 6.1. Alumina, TiO_2, Fe_{Total}, MnO, MgO and CaO all decrease with increasing SiO_2 content. Potash is the only oxide to demonstrate a strong positive correlation with SiO_2. Soda and P_2O_5 do not appear to change in any systematic way. In general, the variations are smooth and continuous and thus indicative of a differentiated, comagmatic suite.

Figures 6.2 and 6.3 give the trace element data for the South Mountain batholith (see also Table 6.1). Like the major element data, this information shows that the degree of differentiation increases from the granodiorites to the 2-mica phases. Within the 2-mica phases themselves, the diagrams indicate that rocks from the western end of the thesis area (i.e. West Dalhousie and Morse Road adamellites) are less differentiated than similar lithologies to the east (Springfield Lake, Lake George and New Ross-Vaughn). Moreover, Sr levels are almost always lower in the Lake

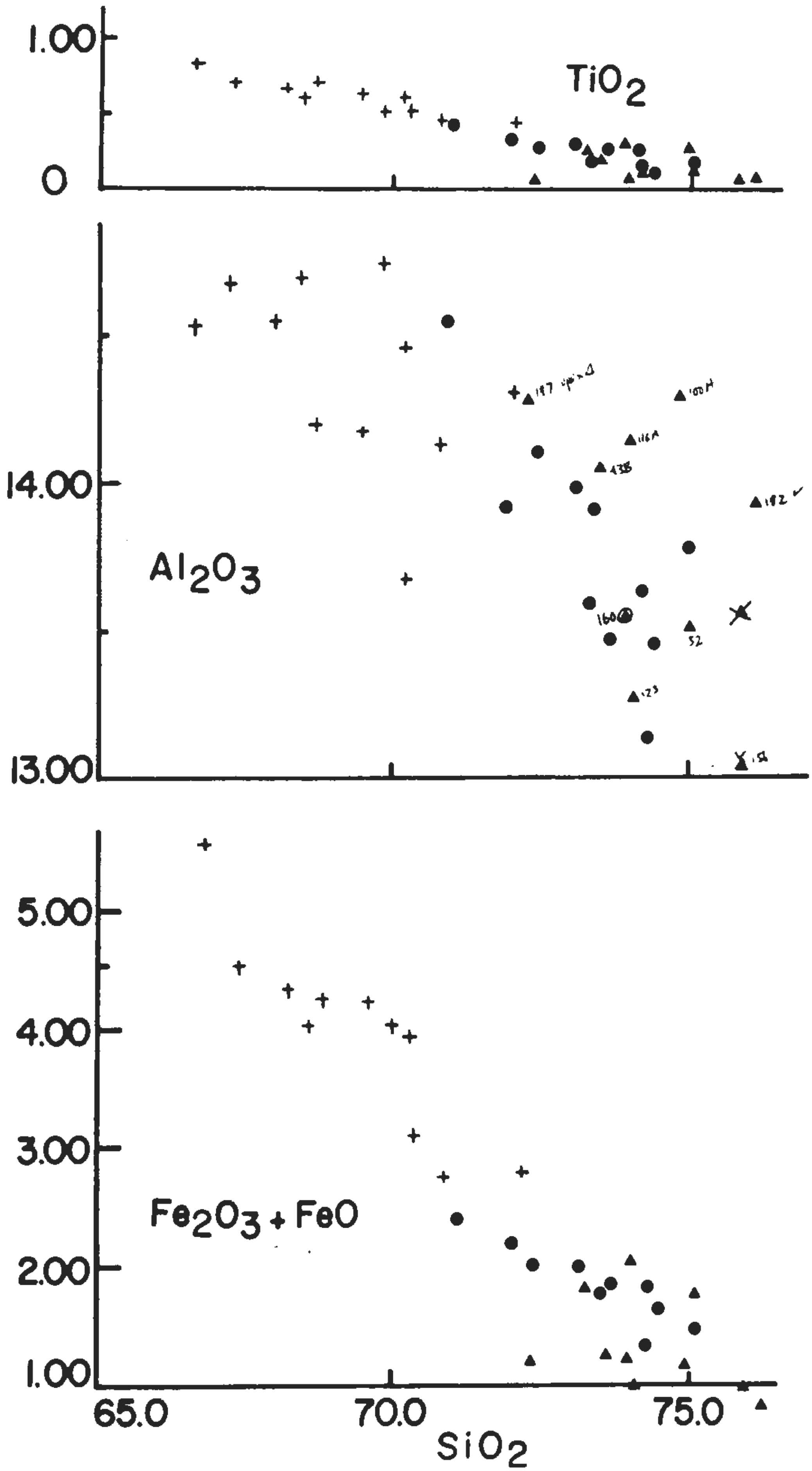
Figure 6.1: Major element variation diagrams. Weight per cent oxides versus weight per cent silica.

Explanation:

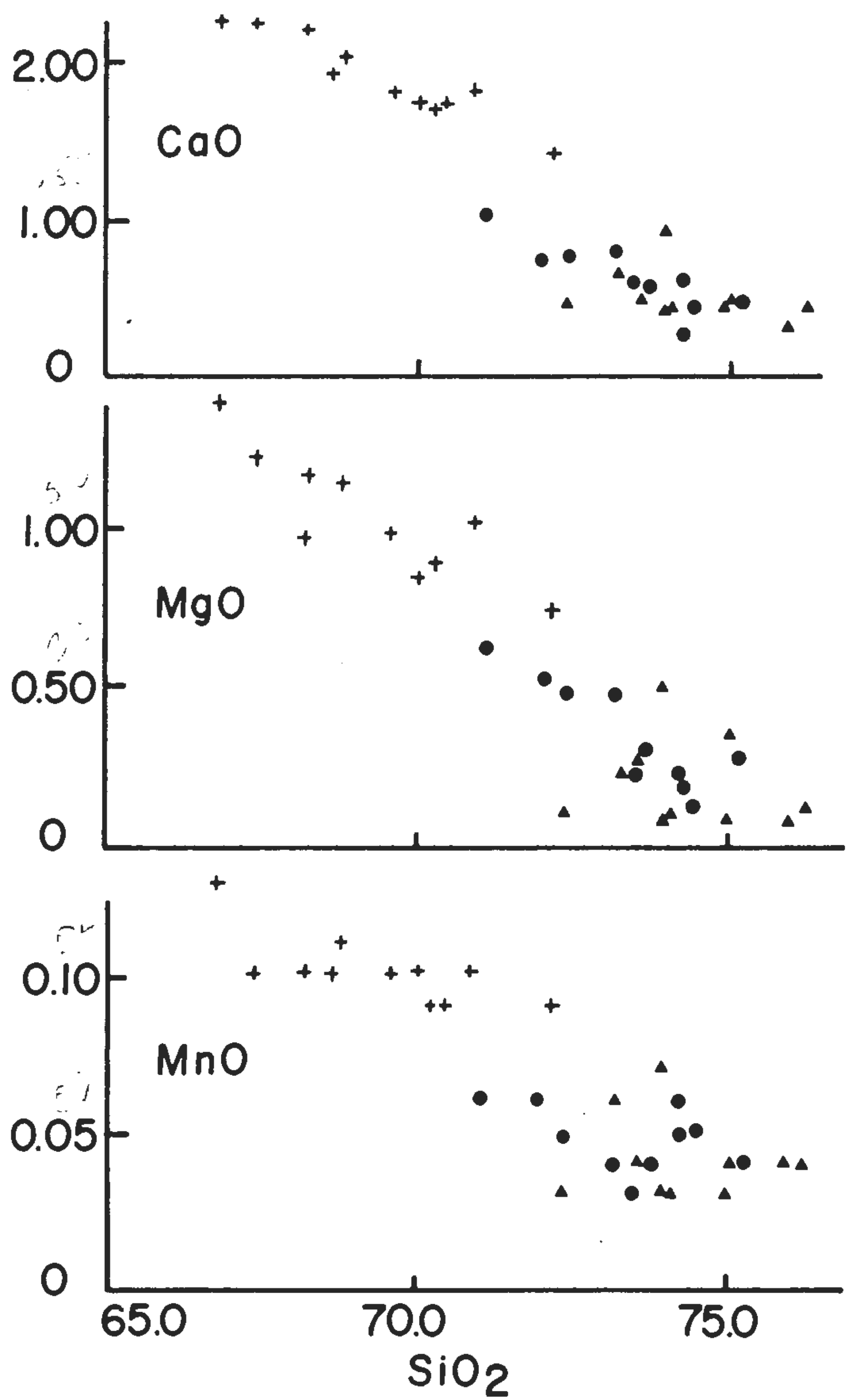
- ▲ Dyke rocks and minor intrusive bodies
- ● Adamellites
- + Biotite granodiorite

Figure 6.2: Trace element ratios versus Thornton-Tuttle differentiation index. Symbols as in Figure 6.1.Circled points indicate West Dalhousie and Morse Road rocks.

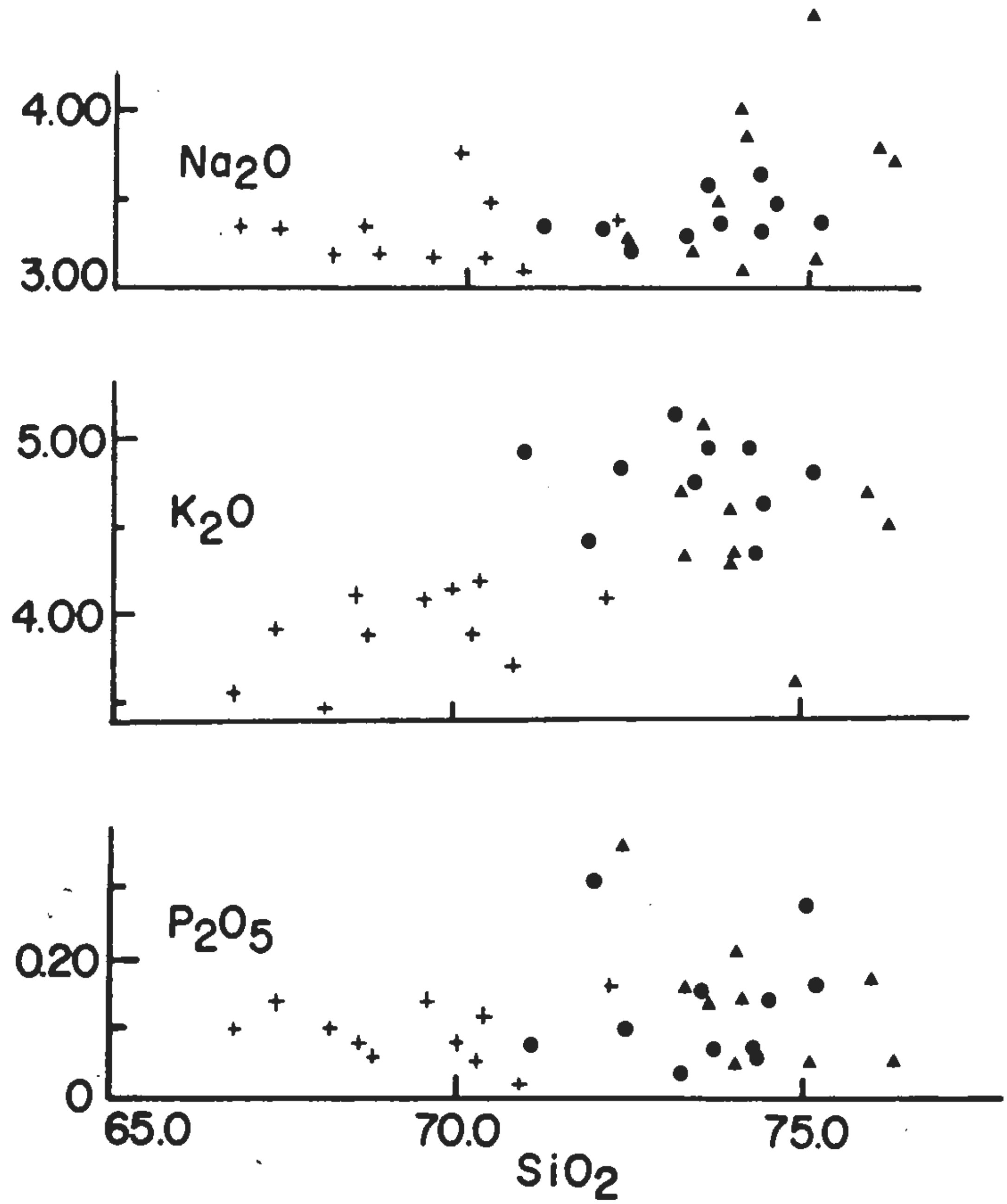
Figure 6.3: Trace element variation diagrams. Zirconium and tin in parts per million versus weight per cent titania and barium in ppm versus rubidium in ppm. Symbols as in Figure 6.2.

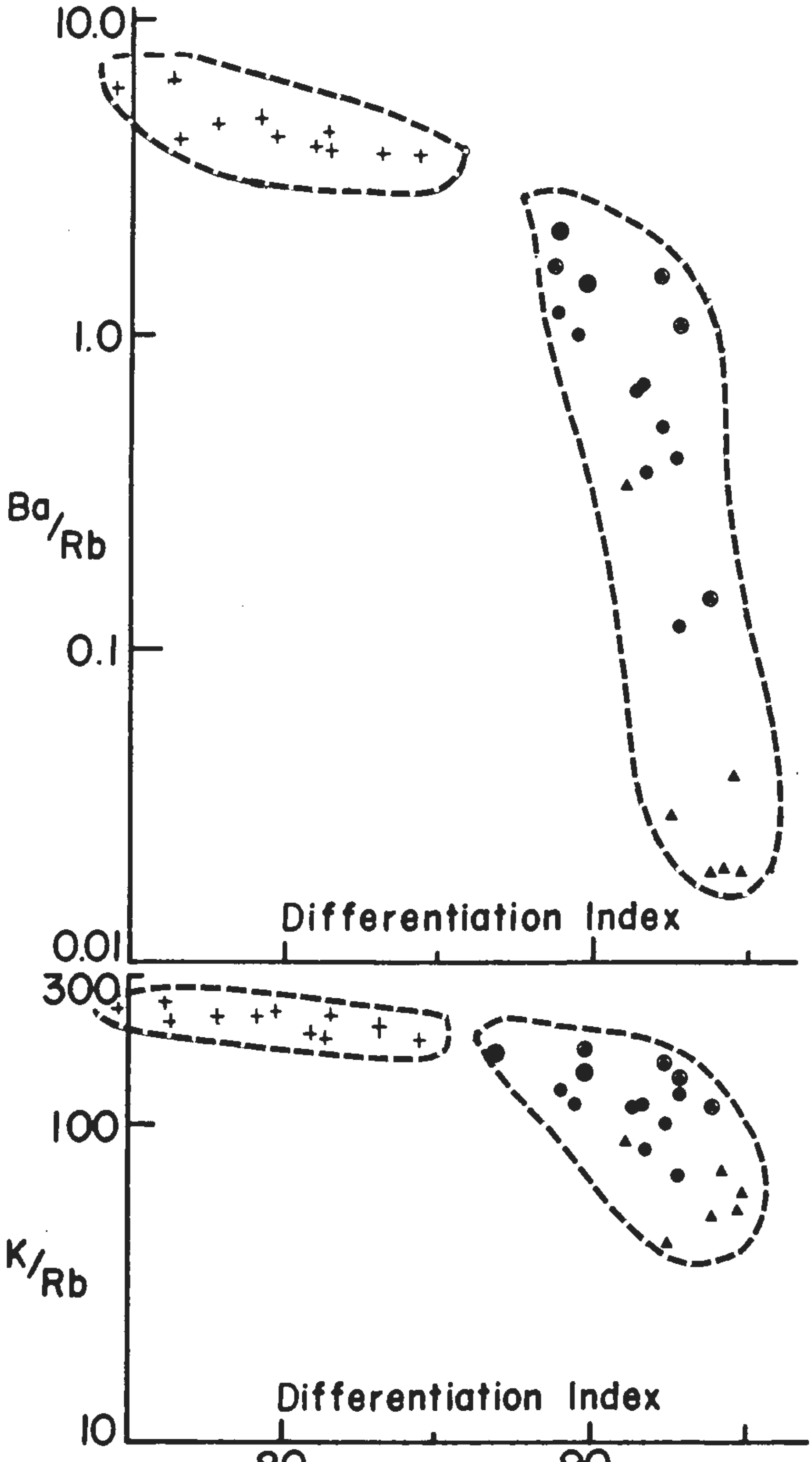


1.00
0
TiO2
14.00
13.00
Al2O3
5.00
4.00
3.00
2.00
1.00
Fe2O3 + FeO
65.0
70.0
75.0
SiO2



CaO
MgO
MnO
2.00
1.00
0
0.50
0.10
0.05
65.0
70.0
75.0
SiO2


4.00
Na2O
3.00
5.00
K2O
4.00
P2O5
0.20
0
65.0
70.0
75.0
SiO2



10.0
1.0
0.1
0.01
Ba/Rb
Differentiation Index
300
100
10
K/Rb
Differentiation Index
80
90

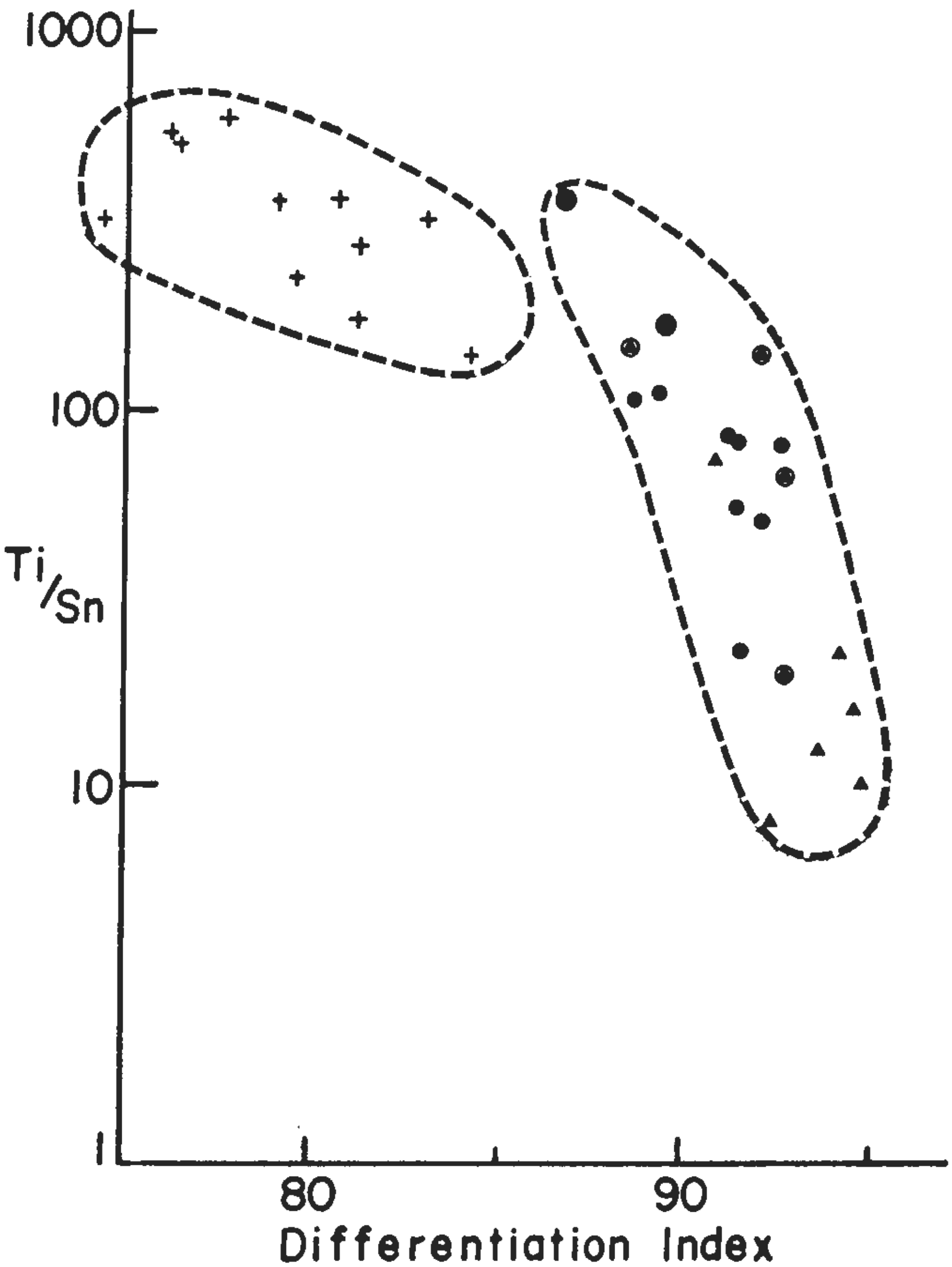
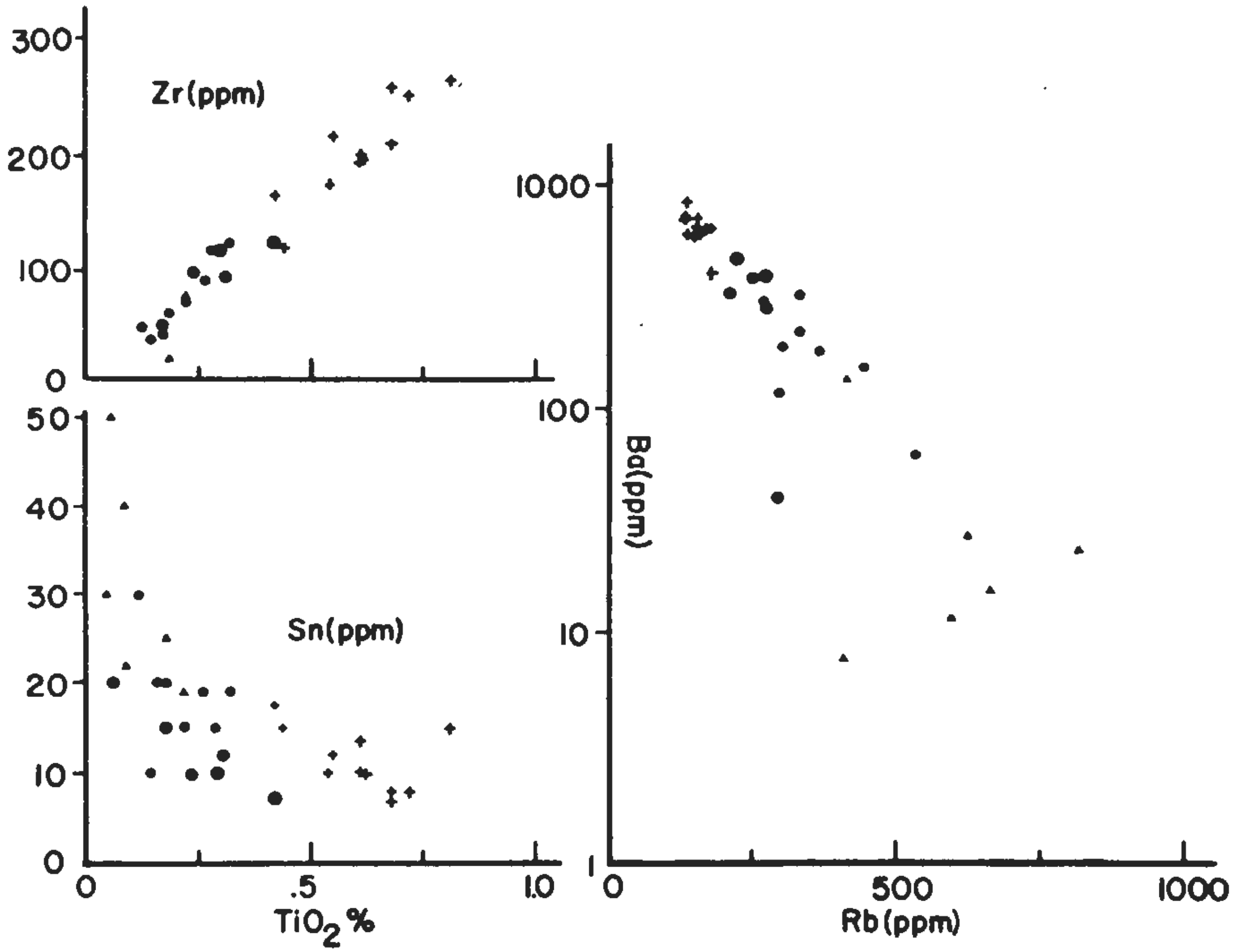


FIG. 6.2



Zr(ppm)
300
200
100
0
Sn(ppm)
50
40
30
20
10
0
0
.5
1.0
TiO_2 %
Ba(ppm)
1000
100
10
1
0
500
1000
Rb(ppm)

FIG 6.3

Figure 6.4: AFM and Na_2O-K_2O-CaO variation diagrams.

Explanation:

- ▲ Dyke rocks and minor intrusive bodies
- ● Adamellites
- + Biotite granodiorite
- s Smith (1973)

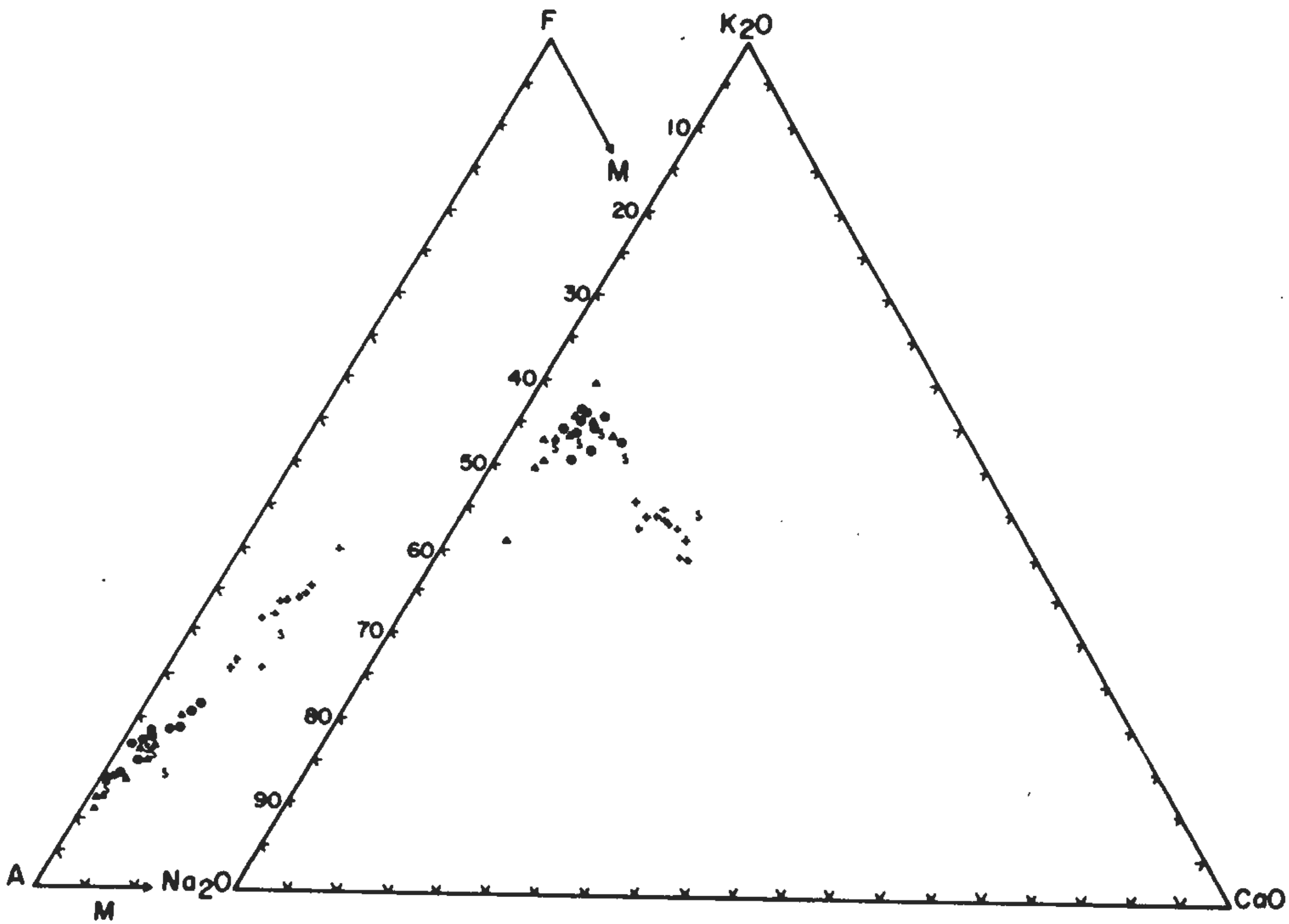


FIG. 6.4

deform them in any way. In addition, the metasediment/granite contacts are sharp and neither migmatites in the country rocks nor gneissic textures in the intrusives are generally developed.

Fyfe (1970) has suggested that brittle processes such as fracture and stoping are the principal means of batholithic intrusion in the upper crust. Abundant xenoliths in the biotite granodiorites demonstrate that these processes probably played an important role in the high level emplacement of the South Mountain batholith.

The gravity model for the batholith (Garland, 1953) may help elucidate the manner in which it rose to high crustal levels. The funnel shape of the pluton is very reminiscent of models produced experimentally by Grout (1945) and Ramberg (1967, 1970). The physical situation modelled by these authors is what is known as a Taylor instability (Elsasser, 1963; Fyfe, 1973). This situation occurs geologically when a density inversion is effected within the earth. The example relevant to this discussion is the formation of a granitic melt at great depths. As a consequence of the density inversion, perturbations develop on the underside of the higher density material. These bulges grow and develop into bulbous bodies which move diapirically upward into the crust. In the lower crust the body rises by plastic deformation of the surrounding rocks (Fyfe, 1970), whereas the brittle processes discussed above take over as the granitic bubble reaches the upper crust.

The emplacement of the adamellite bodies probably occurred soon after they had evolved from the granodiorites. The lack of granodioritic enclaves in the adamellites suggests that they invaded a host which was sufficiently mobile to deform plastically. Indeed, the augen granodiorite observed along the northwestern boundary of the West Dalhousie pluton is evidence that the granodiorites may have responded to adamellite intrusions in this way. Moreover, the scarcity of metasedimentary inclusions in the later rocks implies that they were not required to actively stope the country rocks but rather displaced the granodiorites and abutted against pre-existing granodiorite/metasediment boundaries.

These observations, combined with chemical and mineralogical data discussed elsewhere in this chapter, outline a possible evolutionary sequence for the adamellite pods. The South Mountain batholith was emplaced into high crustal levels as a single body of magma. Subsequent crystal fractionation produced first the biotite granodiorites and then a series of adamellite bodies. Once the adamellitic liquids were evolved, they moved towards the roof of the batholith and so auto-intruded the still not and mobile granodiorites (the vertical distances moved probably did not exceed 5 km). The West Dalhousie and Morse Road plutons represent the early-formed adamellites; they were followed by the Springfield Lake, Lake George and New Ross-Vaughn pods.

IV Depth of Emplacement

The depth of emplacement of the South Mountain batholith can be inferred from several data. In the first place there are a number of field observations to indicate shallow emplacement levels. The biotite granodiorites cross-cut the Lower Devonian Torbrook Formation along the north side of the pluton. The sequence is 1.5 km thick in the thesis area and attains a maximum thickness of 3 km just west of the area. Thus, excluding a consideration of the amount of tectonic thickening in the sequence, the minimum depth of emplacement of the batholith ranges from 1.5 km to 3 km. These depths are well within Buddington's (1959) epizone (0-10 km) classification.

The batholith has other characteristics which indicate its epizonal affinities. The contacts are generally discordant and sharply intrusive, and intrusion was into low grade metamorphics. In addition, the 2-mica phases display features such as miarolitic cavities, granophyric textures and turbid (i.e. reddened) feldspars (Boone, 1969). Taylor (1968, 1971), Taylor and Epstein (1963) and Taylor and Forester (1971) have demonstrated that plutons containing these phenomena have had their O^{18}/O^{16} ratios altered in such a way that it is necessary to invoke the interplay of groundwater with the intrusions. Clearly, such intrusions have been emplaced into high crustal levels.

A plot of the CIPW norms in the Ab-Or-Qz ternary system also implies that the South Mountain batholith rocks equilibrated at low pressures. Figure 6.5A shows the Ab, Or, Qz compositions of the South Mountain rocks recalculated to 100% in relation to ternary minima, eutectics (Tuttle and Bowen, 1958; Luth et al., 1964) and the trend of isobaric univariant points at varying Ab/An ratios (James and Hamilton, 1969). The position of the univariant points at 4 kb is inferred from the suggestion of Winkler (1967) and James and Hamilton (1969) that these points shift towards the Ab apex with increasing pressure in a manner similar to that of the minima and eutectics. It can be seen that most points fall between the 1 kb and 4 kb trends of piercing points. This data combined with the field observations suggest that the batholith was intruded into the lower part of the epizone (i.e. 4-10 km).

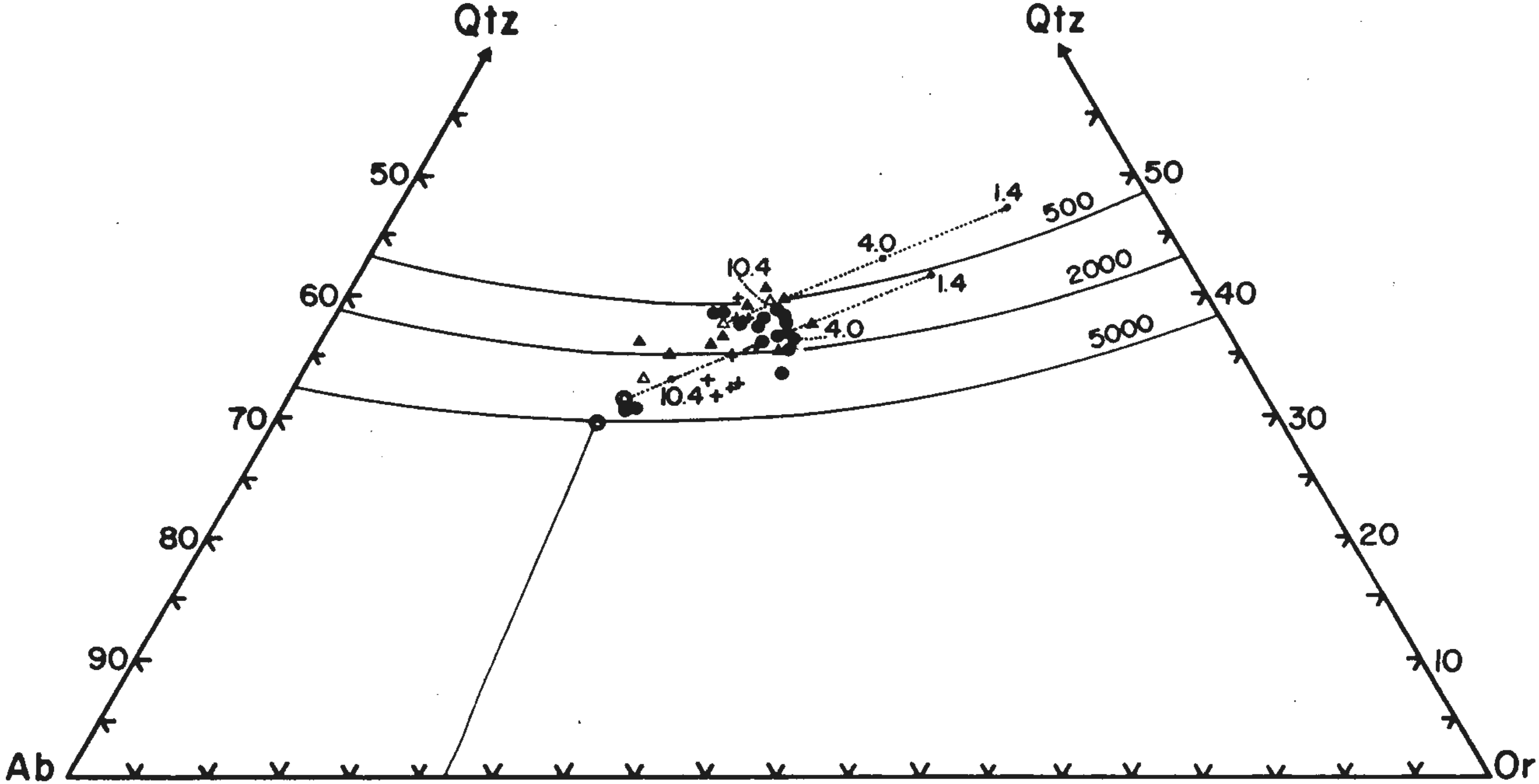
Depth of emplacement information may be gained from an examination of the P,T conditions and phase relations required to crystallize andalusite from the 2-mica magmas. In other examples of andalusite-bearing granitic rocks (Bramall and Harwood, 1932), this mineral has been considered inherited from the metasedimentary envelope. However, there seems to be little doubt in the case of the South Mountain batholith that the aluminum silicate is of igneous origin. In the first place, the 2-mica phases contain very little xenolithic material and many andalusite-bearing rocks are xenolith free. Furthermore, aluminum silicates have not been found associated with xenoliths in either the andalusite-bearing phases or the granodiorites. It also seems likely that any relict andalusite picked up by these

Figure 6.5A: Plot of normative Ab-Qz-Or for South Mountain batholith lithologies. Minima, eutectics and cotectics from Tuttle and Bowen(1958) and Luth et al(1964). Ab/An piercing points after James and Hamilton(1969).

Explanation:

▲	Dykes rocks and minor intrusive bodies
●	Adamellites
+	Biotite granodiorite
△	Ternary minima
⊗	Eutectics
4.0	Ab/An

Figure 6.5B: Plot of normative Ab-An-Or for South Mountain lithologies. Symbols as in Figure 6.5A. M-n is the trend of Sierran Nevadan rocks and a-b is the univariant liquidus curve(after Presnall and Bateman,1973). Other solid lines represent the plagioclase and orthoclase solidus fields.



Qtz
Qtz
50
60
70
80
90
50
40
30
20
10
Ab
Or
1.4
4.0
10.4
1.4
4.0
10.4
500
2000
5000

FIG. 6.5A

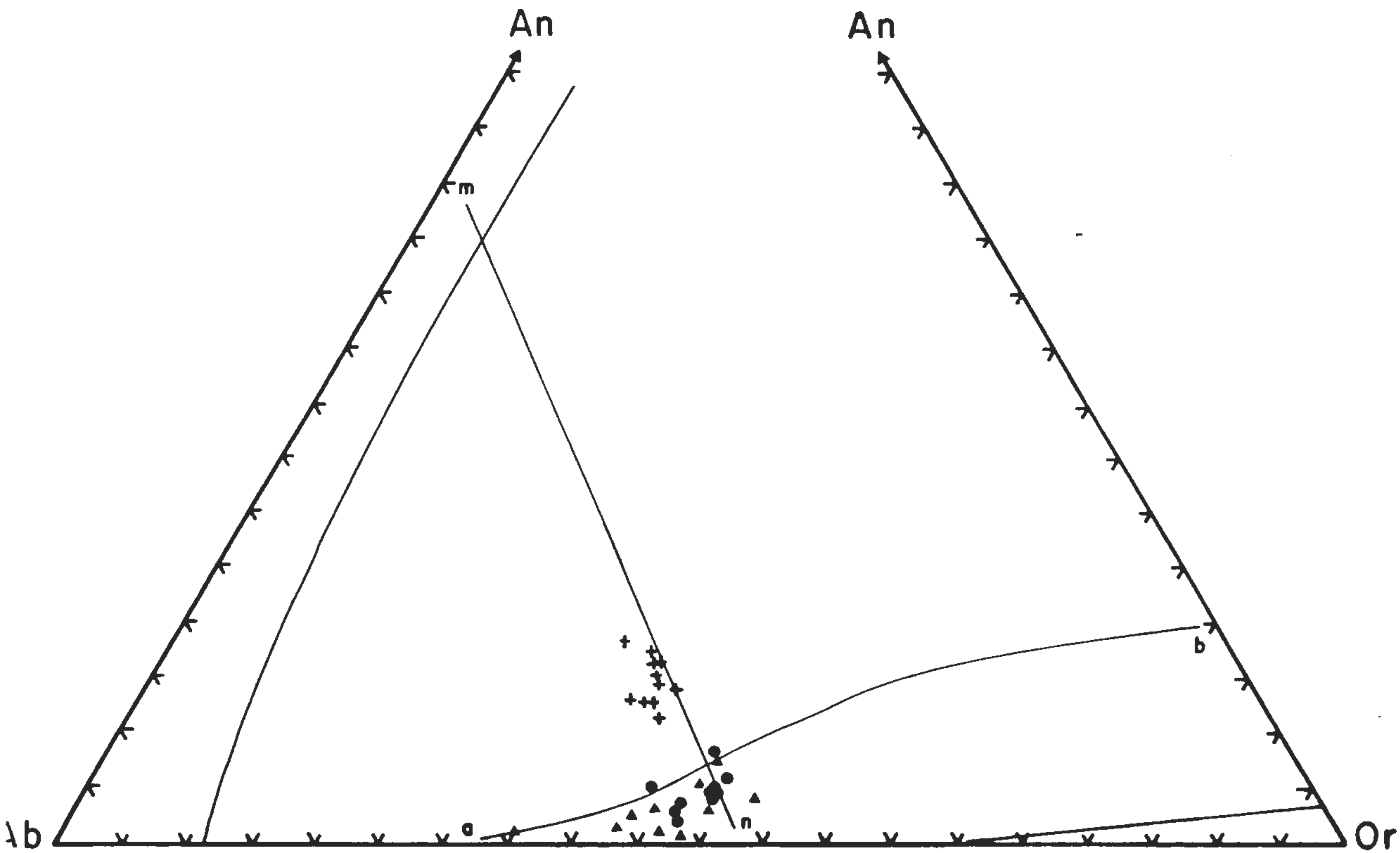


FIG. 6.5B

magmas would have completely reacted with the liquid to form muscovite since all andalusite-bearing phases have been in equilibrium with this phase. More conclusively, andalusite from the contact aureole invariably contains many inclusions, whereas andalusite grains from the granitic rocks are clear and free of included material.

Figure 6.6 is the aluminum silicate phase diagram as determined by Richardson et al. (1969). The wet granite solidus and the muscovite aluminum silicate curve have been added in order to facilitate the discussion. It can be seen from the diagram that for andalusite to be of magmatic origins the melt must have been (1) above the wet granite solidus; (2) above the muscovite stability field; and (3) within the andalusite field. In order to conform to these limitations, the pressures of crystallization could not have exceeded 4 kb. Similarly, temperatures would be restricted to a range of 680°C to 850°C. These restrictions would not hold if in fact sillimanite was the original aluminum silicate crystallized and andalusite was the result of subsolidus transformations. However, there is no petrographic evidence (e.g. pseudomorphs, relict cores) to suggest that this was the case.

The P,T conditions of andalusite crystallization are further confined if the mantling muscovite is also considered to be of magmatic origin. The andalusite-muscovite relations would then indicate a pressure range of 3.9 to 3.3 kb and a temperature interval of 650°C to 680°C. These conditions are shown by the stippled area in Figure 6.6.

Figure 6.6: Aluminum silicate phase diagram as per Richardson *et al*. (1969). Wet granite solidus (Luth *et al*., 1964) and muscovite breakdown curve (Althaus *et al*., 1970) superimposed. Stippled area represents the P,T range of crystallization assuming both andalusite and mantling muscovite to have crystallized from the melt.

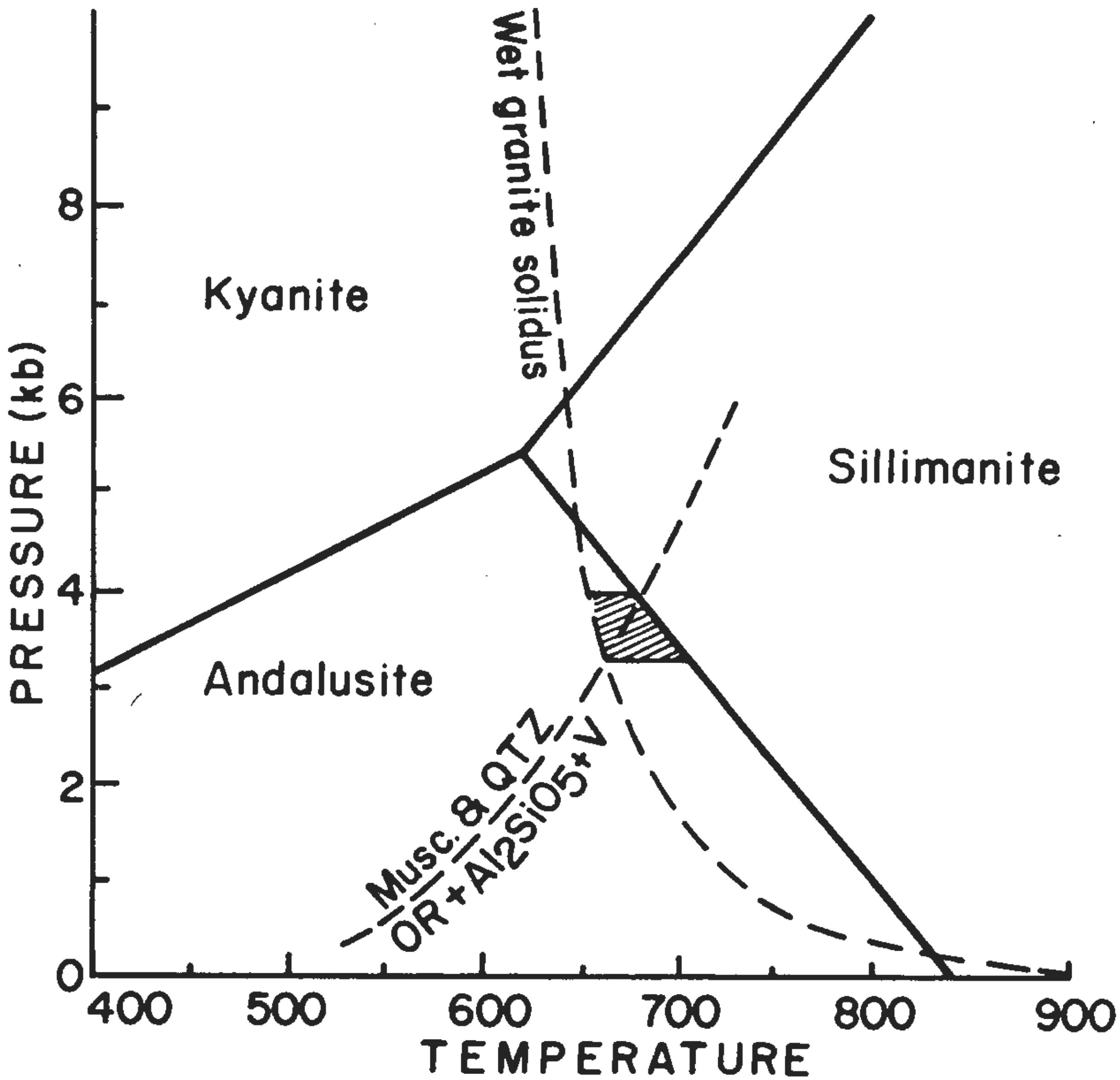

Wet granite solidus
Kyanite
Sillimanite
Andalusite
Musc. & QTZ
OR + Al2SiO5 + V
PRESSURE (kb)
0
2
4
6
8
400
500
600
700
800
900
TEMPERATURE

FIG. 6.6

However, it must be emphasized that at present there are no criteria available for conclusively identifying the mantling mica as either magmatic or subsolidus in origin.

If, in fact, it is true that andalusite is able to crystallize from granitic magmas, then this also places physical constraints on the aluminum silicate stability relations, and particularly the andalusite-sillimanite phase transition boundary. The polymorph boundaries determined by Richardson et al. (1969) are compatible with the petrographic data whereas those of Fyfe (1967), Althaus (1967) and Holdaway (1971) would not permit the crystallization of magmatic andalusite. Accordingly, the work of the former authors appears to be a better approximation of the andalusite-sillimanite phase relations.

It is also interesting to consider the evolution of the magma sequence in the light of the presence of andalusite. Andalusite is not a common granitic accessory; even in peraluminous rocks. Moreover, the South Mountain batholith is not excessively peraluminous in terms of other corundum-normative granites (Groves, 1972). Therefore, the occurrence of this mineral merits discussion as it may have formed under a unique set of chemical, pressure and temperature conditions.

One factor immediately obvious from Figure 6.6 is that andalusite must crystallize from a liquid approximating a water-saturated granite (sensu stricto). The solidi of drier, more basic granitic rocks would not intersect the andalusite stability field. This constraint sheds additional light on the mode of formation of the aluminum silicate-bearing (i.e. 2-mica) phases. Cann (1970) has shown that very wet granitic magmas do not have the ability to rise far from their places of origin. Thus, high-level differentiation from the biotite granodiorites appears to be the simplest way of emplacing the 2-mica phases into high crustal levels.

It has previously been noted that the andalusite is invariably mantled by muscovite. This demonstrates that the muscovite + quartz + orthoclase + aluminum silicate + water phase boundary has been intersected at some point during crystallization. However, since not all muscovite envelops andalusite, it is conceivable that some of the mica was formed before the development of aluminum silicate. The sequence of crystallization could have been the result of a decrease in pressure followed by a drop in temperature. In fact, there is other mineralogic evidence to suggest that at least some of the andalusite-bearing phases have undergone a change in pressure during their evolution. First, andalusite has been found in some of the late aplitic dykes which may owe their textures to pressure quenching. Secondly, it was noted in Chapter 4 that rapakivi textures were common in several of the adamellites. These textures have been interpreted by Whitney (1972) as the result of a pressure decrease (Figure 6.7). Indeed, from Whitney's experimental work it seems necessary that this decrease

Figure 6.7: Phase assemblage diagram for synthetic granite at 750 °C (after Whitney, 1972).

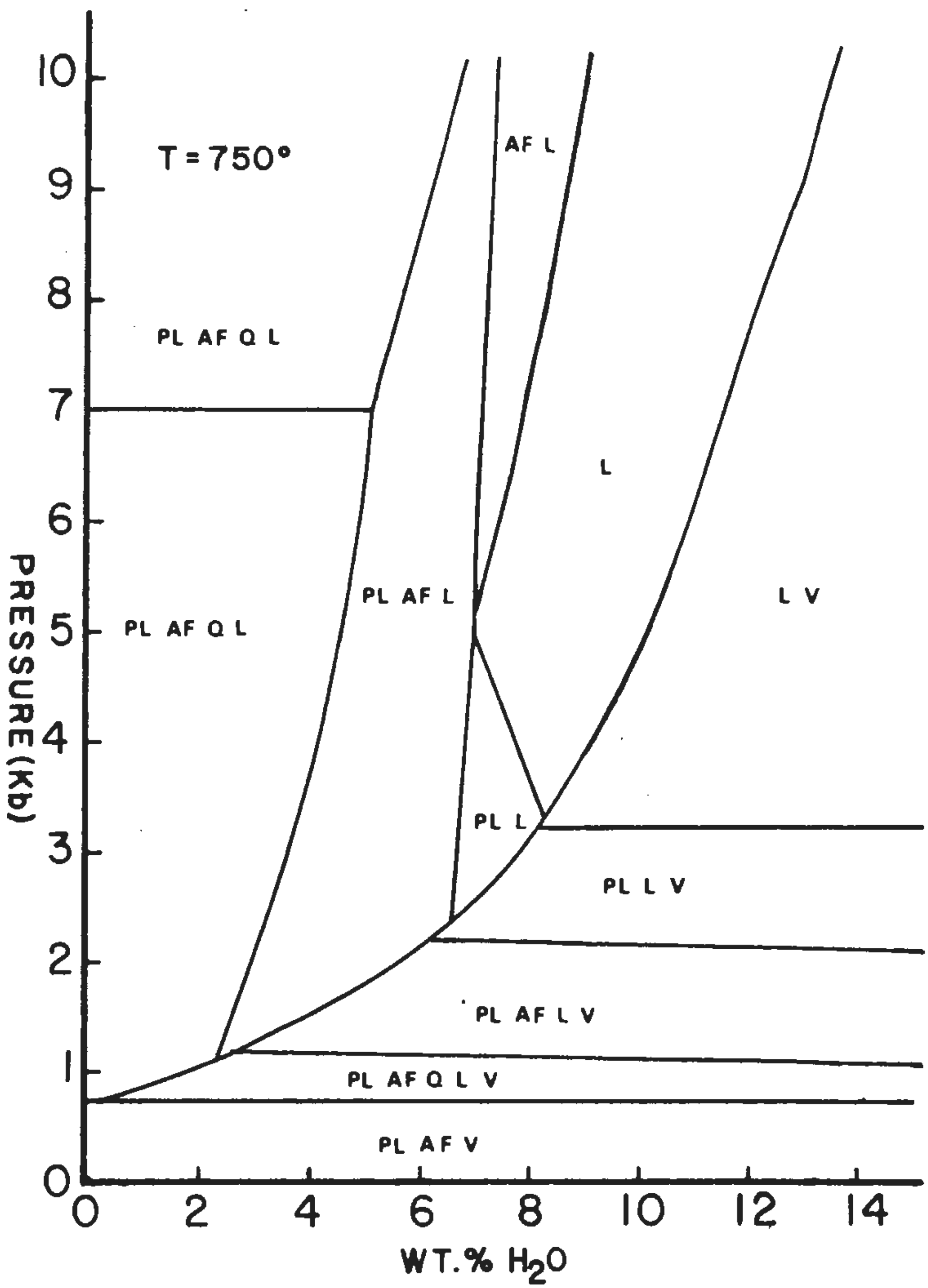

T = 750°
PL AF Q L
AF L
L
PL AF L
L V
PL AF Q L
PL L
PL L V
PL AF L V
PL AF Q L V
PL AF V
PRESSURE (Kb)
WT. % H_2O
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10
12
14

FIG 6.7

occur about a 4 kb pivot point. The phase relations in Figure 6.6 demonstrate that it would be possible to crystallize muscovite above 4 kb, then andalusite and muscovite below 4 kb. Furthermore, Whitney (1972) found that alkali feldspar precedes plagioclase in the crystallization scheme only at water contents approaching the saturation level of the melt. This is also compatible with the picture of the andalusite-bearing magma inferred from Fig. 6.6.

There is also a problem as to why the granodiorites contain no aluminum silicate. During early crystallization, there appears to have been sufficient amounts of Fe_{Total}, Mg and Ca to combine with Al in the production of plagioclase and especially biotite to suppress the formation of an independent aluminum silicate mineral. The positive correlation between normative corundum vs. silica (Fig. 6.8) demonstrates the dependence of alumina oversaturation on the silica content of the rock.

Overall, the depth of emplacement information discussed in the preceding section, though somewhat contradictory, implies that the batholith was emplaced within the upper mesozone/lower epizone region of the crust. Moreover, the P,T conditions for the final stages of crystallization of the 2-mica phases varied from 4 kb, 650°C to 5 kb, 800°C.

V Origin of the South Mountain Batholith Magma

It has long been recognized that granitic batholiths form the cores of most, if not all, the world's orogenic belts. Traditionally, it was believed that the batholiths

Figure 6.8: Normative corundum versus weight per cent silica. Symbols as in Figure 6.1.

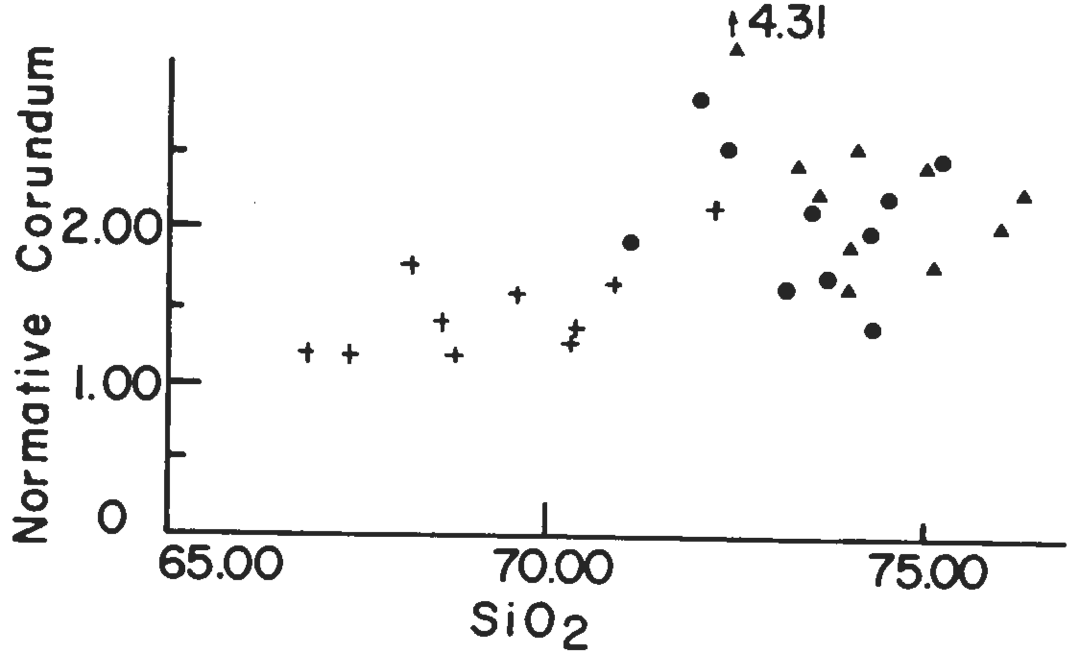


FIG.6.8

were formed by the anatexis of the thickened crust within the mobile zone; however, the advent of plate tectonic theory has made granitic production within the subduction zone a very attractive hypothesis. As the controversy is still being debated, it is not yet possible to generalize on the origins of orogenic granitoids. Each batholith must be discussed on its own merits and decisions on its origins made to fit the particular case.

In order to discuss the origins of the South Mountain batholith in terms of modern petrologic concepts, it may be helpful to review the tectonic framework into which the pluton was emplaced. It is now well accepted that the Acadian orogeny was related to a closing of the Paleozoic Atlantic (Wilson, 1966; Bird and Dewey, 1970; Schenk, 1971). The Siluro-Devonian geology of western Nova Scotia suggests that the closing was effected in a manner analogous to the modern consumption of oceanic crust beneath the circum-Pacific continental and island-arc areas. Thus, the Silurian (New Canaan) calc-alkaline volcanics were associated with the subduction of proto-Atlantic crust. Volcanism (and perhaps subduction) was terminated with the onset of continental collision in the late Lower Devonian to early Middle Devonian. The collision was manifested by the folding and metamorphic events of the orogeny. The invasion of the entire area by granitic plutons may have begun with the folding, but final emplacement was not completed until after the period of deformation.

There seems to be little doubt that the andesitic volcanic/granitic batholith association, whether it be Paleozoic or Cenozoic in age, is related to the subduction of ocean crust beneath continental crust. What is yet unclear, however, is the role played by the Benioff zone in the genesis of the calc-alkaline volcanic/plutonic suite. At present, there are four models capable of explaining the observed spatial, temporal and petrologic relations of the orogenic magmas. The pros and cons of each model are discussed in the following paragraphs and the one most suited to the South Mountain batholith situation is chosen.

1. Melting of the subducted lithospheric plate

This model proposes the direct involvement of the Benioff zone in the generation of calc-alkaline magmas. Various authors (Green and Ringwood, 1968; Hamilton, 1969; Dickinson, 1970; Kistler and Evernden, 1971; Church and Tilton, 1973; Huang and Wyllie, 1973) have postulated that partial melting of subducted basaltic crust and pelagic sediments is able to give rise to andesites as well as the more acid members of the suite. One of the strongest indications of subduction zone participation in magma production is the well-known K_2O variation across continental margins. Dickinson (1970) and James (1971) have shown that the landward increase of K_2O in calc-alkaline magmas is directly proportional to the depth of the underlying seismic zone. This trend, though not universally accepted (Kistler and Peterman, 1973), has been attributed to the successive breakdown of various hydrous minerals furnishing water for magma generation.

Thermal models (Oxburgh and Turcotte, 1970; Toksoz et al., 1971), isotope studies (Church and Tilton, 1973) and experimental petrology (Green and Ringwood, 1968; Huang and Wyllie, 1973) have also been employed to list the general applicability of deriving the orogenic magmas by this mechanism. Overall, the model has borne up under scrutiny, but because of great deficiencies in our current knowledge of processes in the mantle regime, much of the data is equivocal. Perhaps the most convincing argument for deriving andesites from the subduction zone is their Pb and Sr isotope data. Church and Tilton (1973) have reviewed the Pb and Sr isotope information for andesites and found it to be compatible with an anatexis of basaltic material origin. This circumvents the problem of having to contaminate island-arc andesites with crustal material in order to produce the initial ratios seen in andesites. Unfortunately, the isotope data for calc-alkaline intrusives does not usually present such a clear-cut case. The initial ratios of orogenic batholiths are often significantly higher than those of the andesites (Hurley et al., 1965; Dickinson, 1970) and thus are still open to interpretation.

Anatexis in subduction zones may be the best explanation of andesite genesis currently available, but the model still has shortcomings in accounting for the associated granitic batholiths. For example, this model does not explain the absence of orogenic granites in island arc environments which are not underlain by continental crust. Moreover, in a recent chemical and isotopic study of the Sierra Nevada batholith, Kistler and Peterman (1973) refuted the idea of a systematic change in K_2O across the body and expressed doubt that the observed initial Sr^{87}/Sr^{86} ratios of the granites could have been inherited from a basaltic parent.

In the context of the South Mountain batholith, the model encounters other difficulties. In the western Americas calc-alkaline extrusives and intrusives are roughly equivalent not only in time and space, but also in composition (Cobbing and Pitcher, 1972; Hamilton, 1969; Dickinson, 1970). This has been interpreted as being consistent with a common source for these magmas. The South Mountain batholith, however, is not temporally related to the nearby andesites nor is its overall composition in any way andesitic. Indeed, assuming the batholith to be comprised of 75% biotite granodiorite (average SiO_2: 69.5%) and 25% 2-mica phases (average SiO_2: 73.5%), the original magma may have contained approximately 70% SiO_2.

2. Wet melting of mantle peridotite

Recent experimental studies by a number of authors (O'Hara, 1965; Kushiro, 1969; Yoder, 1969) have demonstrated that silica-rich liquids may be produced by the partial fusion of synthetic mantle compositions under "wet" conditions. For example, in the system forsterite-diopside-quartz under dry conditions, mantle compositions cannot produce quartz-bearing melts because the diopside-enstatite thermal divide prevents mantle-derived partial melts from fractionating into the quartz stability field. However, under wet conditions the divide is bridged by the olivine primary phase field and quartz-rich liquids may be formed. The role of the subduction zone in this process is to supply water (either from pore fluids in subducted sediments or from the breakdown of hydrous minerals) to the mantle for "wet" melting.

Fractional crystallization is also an integral part of this model. The original liquids produced are andesitic; subsequent differentiation gives rise to the dacitic and rhyolitic compositions commonly found in the calc-alkaline suite.

There are several arguments, however, to suggest that this mechanism is not applicable to the generation of calc-alkaline rocks in general and the South Mountain batholith in particular. Presnall and Bateman (1973) have pointed out that while andesites are common in the oceanic environment, granitic batholiths are rarely found outside the continental regime. This is not compatible with a common mantle origin for these rocks since it implies that sialic crust is necessary for the formation of the acid intrusives. The model also cannot account for the initial Sr^{87}/Sr^{86} ratios of island arc andesites. Both these rocks and their continental arc equivalents have initial ratios which are higher than mantle values (Church and Tilton, 1973). In the case of the continental arc volcanics, the crust is a readily available radiogenic contaminant; in island arc situations no such contaminant exists.

A second difficulty is the maximum depth to which water from the subduction zone is available for melting. Wyllie (1973) felt that a descending (45°) lithospheric slab would give up most of its water by 100 km; Boettcher (1973) considered wet melting of the mantle a possibility to 60 km. Thus it is problematic for anatexis in the mantle to supply magmas at sufficient distances from the trench to account for Dickinson's (1971) arc-trench gap.

Mantle material is an even less likely source of the South Mountain batholith. As previously noted, the batholith is neither temporally nor compositionally related to the nearby andesites.

Furthermore, there are no mineralogical indications that the magmas originated in the mantle. Rare garnets (almandine ?) do occur in the granodiorites, but they have also been observed in the contact aureole, in xenoliths and in a few aplite dykes. As yet these garnets have not been analyzed and it is not known whether one or more varieties exist. Thus, while further investigation of this constituent may shed light on the source of the magmas, at present no petrogenetic conclusions may be drawn from its presence.

3. Partial melting in the crust

Despite the magma producing potential of the subduction zone, a number of workers (e.g. Brown and Fyfe, 1970; Fyfe, 1970; Brown, 1973; Hall, 1972, 1973; Fyfe, 1973; Presnall and Bateman, 1973) have maintained that granitic batholiths are the result of anatexis within the crust. There are several reasons for favouring crustal origins for granitic rocks. In the first place, the crust contains ample material of granitic composition. Moreover, various experimental studies (Tuttle and Bowen, 1958; Winkler, 1967; James and Hamilton, 1969; Brown and Fyfe, 1970; Robertson and Wyllie, 1971) have shown that the P,T conditions necessary to melt sialic material are compatible with conditions attained in the lower crust. Partial fusion could be initiated by a thickening of the crustal prism in the orogenic zone or induced by heat supplied from rising andesitic magmas (Brown, 1973; Presnall and Bateman, 1973).

The intermediate initial Sr^{87}/Sr^{86} ratios of orogenic granites (Hurley *et al*., 1965; Fairbairn *et al*., 1964) present some difficulty to the crustal anatexis model. On the strength of these values many authors (Dickinson, 1970; Mursky, 1972; Floyd, 1972; Kistler *et al*., 1971) have concluded that orogenic batholiths could not originate in the crust. However, it has also been pointed out (Peterman *et al*., 1967; Kistler and Peterman, 1973) that crustal materials with suitable intermediate initial ratios may in fact exist. Indeed, Kistler and Peterman (1973) have considered Sierra Nevada granites with initial ratios of .706 or more to be of crustal derivation.

The crustal fusion model apparently accounts for most of the features of the South Mountain batholith. The rather acid composition of the batholith and the peraluminous nature of the magmas are chemical characteristics that could easily be inherited from crustal rocks. The hiatus between the Silurian volcanics and the granitic rocks also lends itself to interpretation by this model. As Brown (1973) and Presnall and Bateman (1973) have suggested, rising andesitic magmas may transfer heat for melting to the crust during their ascent. Presnall and Bateman (1973) have reckoned that the temperature of these magmas on reaching the lower crust would be between 1150°C and 1450°C--clearly sufficient for partial melting. The formation of a "sticky" melting zone may effectively shut off the rise of the andesitic magmas. Underplating of the crust would then occur, with the result that more heat would be available for fusion. This sequence of events is compatible with the timing of igneous activity in western Nova Scotia.

Fairbairn et al. (1964) have found an initial Sr^{87}/Sr^{86} ratio of .708 $\pm$ .003 for the South Mountain batholith. This is similar to values reported for other orogenic granites (Hurley et al., 1965; Peterman et al., 1967; Floyd, 1972; Kistler and Peterman, 1973) and, as discussed above, the petrogenetic significance of such ratios remains somewhat unclear. Thus, on purely isotopic evidence alone, the lower crust cannot be excluded as a possible source for the batholith.

4. Crustal contamination of a mantle-derived magma

As processes are always complex in nature, a hybrid of models 1 and 3 might also be considered. By mixing andesitic melts with suitable amounts of sialic crustal material, intrusives of the desired chemical composition and isotopic constitution could be produced. Looking at some approximate figures may help show what this mixing model means in terms of the South Mountain batholith. An average andesite contains roughly 55% SiO_2; the average composition of the batholith has been approximated at 70% SiO_2; and a ternary minimum granite has, as an upper limit, 75% SiO_2. From these numbers it is apparent that the andesitic component would only be about 25% of the bulk composition. A further consequence is that the initial Sr^{87}/Sr^{86} ratio of the crustal material would be rather low (<0.710). Thus, while a mixing model is a distinct possibility, it seems that crustal material would still be the largest contributor to chemistry of the batholith.

VI Summary

Acid plutonism in western Nova Scotia was initiated in the lower crust by the heating effects of Silurian andesitic magmas. As partial melting proceeded, andesitic volcanism was shut off and the subsequent underplating of the melting zone made more heat available to the crust for fusion.

With the collection of sufficient molten material, the granodioritic to transitional granodioritic magma was able to rise diapirically into the upper crust. Intrusion began with the plastic deformation of the deeper crustal levels, but final emplacement was by fracturing and stoping of the country rock. Penetration into the crust terminated at depths in the order of 10 km.

Contemporaneous with emplacement or soon following it, was the evolution of at least five adamellite plutons by fractional crystallization. The pods autointruded the granodiorites and crystallized sequentially; the last pod to form being associated with the central conduit of the batholith. Further fractionation produced a series of dyke rocks and minor intrusive bodies which represent the final magmatic stages in the batholith's development.

Table 6.1

K_2O indices and trace element ratios

Biotite granodiorites

Sample No.	K_2O Index	K/Rb	Ba/Rb	Ca/Sr	Ba/Sr	Ti/Sn
M72-39	152.2	203.6	4.0	104.4	5.2	360.0
53	174.1	249.0	6.6	92.9	4.9	537.5
54E	163.8	240.9	6.2	112.9	5.3	320.0
60	163.8	213.3	3.9	107.9	5.5	320.0
72	173.7	229.0	4.9	94.4	5.0	360.0
86	165.2	199.2	3.9	108.6	5.7	275.0
124	162.6	225.0	4.7	93.6	4.3	600.0
127	148.5	192.6	2.4	91.5	3.8	138.9
137	149.1	217.5	5.6	90.8	4.2	512.5
172	144.0	227.4	4.5	85.8	4.0	173.3
192	165.0	234.9	4.3	117.9	5.6	225.0

Adamellites

Sample No.	K_2O Index	K/Rb	Ba/Rb	Ca/Sr	Ba/Sr	Ti/Sn
M72-50	181.6	156.2	1.5	121.5	8.9	170.0
82	187.7	184.3	2.2	196.6	12.3	357.1
102	171.1	123.7	.70	-	-	84.2
114	155.6	72.2	.12	-	-	23.3
119	150.2	120.5	.67	-	-	86.7
121	148.1	88.8	.37	-	-	55.0
161	176.3	123.7	1.05	-	-	113.1
166	167.2	137.8	.42	-	-	80.0
176	164.1	139.4	1.2	253.0	14.0	105.5
189	157.6	108.7	.53	-	-	50.0

Dyke rocks and minor intrusive bodies

Sample No.	K_2O Index	K/Rb	Ba/Rb	Ca/Sr	Ba/Sr	Ti/Sn
M72-43B	175.5	155.5	1.1	148.7	11.6	66.7
52	175.4	173.2	1.6	100.1	11.5	140.0
100A	120.0	74.7	.02	-	-	22.7
116A	150.2	54.8	.02	-	-	12.5
123	148.6	58.1	.04	-	-	16.0
156	149.0	64.7	.02	-	-	10.0
160	165.7	94.6	.34	-	-	72.2
182	145.2	125.3	.15	-	-	20.0
197	159.5	44.8	.03	-	-	8.0
198	157.9	188.4	1.7	141.5	1.7	150.0

CHAPTER 7: AGE RELATIONS

I Introduction

Field relations, paleontological evidence and radiometric age dates establish that the South Mountain batholith was emplaced during the Middle and Upper Devonian, after the folding and metamorphism of the Acadian orogeny. The average radiometric age for the pluton of 370 m.y. agrees well with late Acadian plutonism elsewhere in the northern Appalachians (Fairbairn, 1971).

The various granitic phases in the batholith have not yet been delineated by dating methods. Chemistry and field relations suggest that the intrusive sequence followed the pattern, granodiorite-adamellites-dykes and minor intrusions; however, the timing of these events is still a point of conjecture.

II Paleontological Age

Along the north side of the batholith, biotite granodiorite intrudes rocks of the Lower Devonian Torbrook Formation. The diverse fossil assemblage indicates that sedimentation continued at least into Emsian times (L. Jensen, personal comm.). In a few localities fossiliferous beds have been observed at the contact, so that there can be little doubt that the batholith post-dates the Lower Devonian.

Overlying the granitic rocks are Horton group redbeds of Lower Carboniferous age. The complete lack of intrusive features and the few granite pebble conglomerates in this sequence indicate that granitic emplacement had ended before earliest Hortonian times (i.e. Tournaisian).

In terms of the Geological Society Phanerozoic time scale (1964), the above information implies that the batholith was emplaced between 370 m.y. and 345 m.y. However, considering the presence of a few, thin tuffs within the Lower Devonian sequence, igneous activity may actually have begun earlier than 370 m.y.

III Radiometric Age

Various groups of workers (Fairbairn *et al*., 1960; Rowden, 1960; Fairbairn *et al*., 1964; Leech *et al*., 1963; Reynolds *et al*., 1973; Cormier and Smith, 1973) have employed radiometric techniques to date the South Mountain batholith. Table 7.1 summarizes the age data currently available. The associated rock types are, for the most part, inferred from mapping done in this study. The compilation shows that the mean age of 20 dates is 363 $\pm$ 28 m.y. and that there is essentially no difference between the average ages from within or outside the thesis area. These dates are also in general agreement with the paleontological information.

Reynolds *et al*. (1973) have dated the Acadian metamorphic event in western Nova Scotia at a minimum of 390 m.y. On the basis of these data, they suggest that the Silurian-Devonian boundary should be placed at 415 m.y. instead of the currently accepted 395 m.y. This would allow sufficient time for deposition, lithification and metamorphism of the Lower Devonian sequences. Fairbairn (1971) has reached a similar conclusion from a regional study of Appalachian intrusives and he favours placing the boundary at 410 m.y. If there is indeed merit in this idea, then granitic emplacement could have begun about 390 m.y. ago and igneous activity may have been initiated as early as 415 m.y. ago.

In fact, the timing of the Acadian events seems to be well-dated if the older Silurian-Devonian boundary is assumed correct. Sedimentation ended with the onset of folding and metamorphism which took place during the Middle Devonian. Post-orogenic granitic emplacement was then completed in the Upper Devonian.

The previously discussed average ages do not include the work of Cormier and Smith (1973). These authors report two age groups of granitic rocks on the basis of Rb-Sr dating. The older group lies on a 417 $\pm$ 38 m.y isochron whereas the age of the younger rocks is 355 $\pm$ 6 m.y. These data are not easily reconcilable with either the above radiometric ages or the paleontological limitations. It is interesting to note, however, that fitting a single line to Cormier and Smith's data yields an isochron age of 352 $\pm$ 7 m.y.

Fairbairn et al. (1964) have found an initial Sr^{87}/Sr^{86} ratio of .708 $\pm$ .003 for the South Mountain batholith. The petrogenetic implications of this value have been discussed in Chapter 6. The initial Sr^{87}/Sr^{86} ratios determined by Cormier and Smith (1973) are given in Table 7.1. As with the associated isochron ages, they are not easily explicable in light of other data and thus were not included in the discussion.

IV Internal Ages

Table 7.1 also shows the existing age data in respect to the various phases of the batholith. It can be seen that the adamellites are not distinguishable from the granodiorites on the basis of age. The interesting feature to note concerning the dates is that the 2-mica rock ages encompass a much wider range than the granodiorite ages. Indeed, both the youngest and oldest ages determined for the batholith are from these phases. It may be significant that the adamellites, dyke rocks and minor intrusives are generally more altered than the granodioritic rocks, but the precise effects of this alteration on the derived ages are not presently known.

On the basis of field, petrographic and chemical evidence it would appear that the adamellites are younger than the granodiorites (Chapters 4 and 6). Similar field and chemical characteristics have been observed in Cenozoic batholiths from the western Americas, where older, basic rocks enclose younger, more acid varieties (Tilling, 1968; Dickinson, 1970; Cobbing and Pitcher, 1972; Brown, 1973).

V New Age Determinations

Five new age determinations for the South Mountain batholith have been obtained from biotite separates using the Ar^{39}/Ar^{40} dating method. The new dates and the rock types on which they were performed are given in Table 7.2. These ages are generally compatible with the pre-existing data; however, M72-39, a biotite granodiorite, has an anomalously low age. This is not thought to represent the intrusive sequence but rather to be a resetting phenomenon effected by the nearby Greywood minor intrusive body.

VI Summary

Although magmatism may have been initiated during the Lower Devonian, emplacement of the South Mountain batholith was not completed until the Middle and/or Upper Devonian (circa. 370 m.y.).

It is not yet possible to date the various intrusive events (and thus the time span of emplacement) implied for the batholith. On the basis of field evidence and chemistry the biotite granodiorites are post-dated by the adamellites and both, in turn, are cut by dykes and minor intrusives (which, however, yield the oldest radiometric ages). New age data are required to help unravel the emplacement sequence.

The initial Sr^{87}/Sr^{86} ratio for the South Mountain batholith is $.708 \pm .003$.

Table 7.1

Radiometric Dates from the South Mountain Batholith

Rock Type/Reference	Granodiorite	Adamellite	Dyke Rocks and Minor Intrusives	Range	Average
Within the thesis area (see Map 1)					
Fairburn et al (1960)	350±35 365±36 365±36 365±36 365±36 370±37	355±36		350-405	368±34
G.S.C. (1960, 1963)	363±30	384±30	405±30		
Outside the thesis area					
Fairbairn et al (1960)	370±37	370±37 380±38 345±34 355±36			
G.S.C. (1963)			396±30	345-396	368±23
Reynolds et al (1973)	364±4 366±4 367±4 369±4				
Range	350-370	345-384		345-405	368±28
Average	364±24	365±35	400±30		

Table 7.1 (continued)

Cormier and Smith (1973)*	Isochron age (m.y.)	$(^{87}Sr/^{86}Sr)_o$
Porphyritic quartz monzonite	417 ± 38	0.702 ± 0.005
Muscovite-biotite granite	387 ± 25	0.703 ± 0.007
Alaskite		
a) Halifax-St. Margaret's Bay area	357 ± 10	0.702 ± 0.008
b) New Ross area	350 ± 7	0.714 ± 0.006
c) All samples combined	355 ± 6	0.708 ± 0.005

* The granitic rocks of the Halifax-St. Margaret's Bay area are thought to be an eastward extension of the New Ross-Vaughn complex.

Table 7.2

Ar^{39}/Ar^{40} ages from the South Mountain Batholith

Sample No.	Rock Type/Pluton	Temperature °C	%Ar^{39} Released	Age m.y.	Mean Plateau Age m.y.
M72-39	biotite granodiorite	400	1.25	233	
		650	39.50	357	
		750	21.00	360	359 ± 6
		850	33.00	362	
		950	5.00	358	
M72-50	porphyritic adamellite/ West Dalhousie	400	4.75	347	
		650	34.50	379	
		750	18.00	381	380 ± 10
		850	40.50	380	
		950	.75	378	
M72-119	"fresh" adamellite/ New Ross-Vaughn	400	7.75	301	
		650	21.50	369	
		750	20.00	376	374 ± 11
		850	45.25	372	
		950	5.50	395	
M72-160	porphyry/New Ross-Vaughn	400	5.50	283	
		650	8.00	393	
		750	26.25	376	380 ± 12
		850	53.75	378	
		950	6.75	376	
M72-161	medium-grained adamellite/ New Ross-Vaughn	400	1.00	233	
		650	44.75	380	
		750	8.75	379	380 ± 8
		850	39.50	381	
		950	5.75	377	

CHAPTER 8: ECONOMIC GEOLOGY

I Introduction

All but one of the mineralized areas in the South Mountain batholith occur within the New Ross-Vaughn complex. The mineralization is generally of the Sn, W, Mo association and occurs with late-stage pegmatites and greisen zones. Small amounts of fluorine, lithium, radioactive and sulphide minerals are also common. Unfortunately, no economically viable deposits have yet been found (Taylor, 1969).

Besides being the only adamellite body to show significant mineralization, the New Ross-Vaughn pluton also has a number of characteristic petrological, geochemical and geophysical parameters that make it unique in the batholith. This suggests that the Sn, W, Mo mineralization is restricted to a specific geological environment. Recognition of this environment elsewhere may help uncover new mineral localities.

Manganese mineralization is found in the biotite granodiorites north of New Ross, Lunenburg Co. The ore is associated with a northeast trending fault. Again the deposits are small and, at present, are of no commercial value (Taylor, 1969).

II Mineralization in the New Ross-Vaughn Complex

Mineralization in the South Mountain batholith occurs, for the most part, in association with late-stage pegmatites and greisen zones. Known occurrences of this type are found within the New Ross-Vaughn adamellite complex (Fig. 2.3). The mineralized dykes contain enrichments of Sn, W or Mo, generally in the form of cassiterite, scheelite and molybdenite respectively. A host of other minerals (e.g. fluorite, tourmaline, lepidolite, topaz, monazite, beryl, columbite, tantalite, wolframite, amblygonite, durangite, gummite, malachite, bornite, chalcopyrite, azurite) may also be present, although the more complex parageneses are usually with the Sn, W occurrences rather than the Mo occurrences. Table 8.1 lists the various mineral localities and gives a brief description of their character.

The pegmatite and greisen zones are often associated with alaskitic rocks (Chapter 5). The pegmatites are coarse- to very coarse-grained assemblages, consisting primarily of quartz, potassic feldspar and muscovite. In many cases, they are probably segregations of the alaskite host. The trends of the dykes and zones of greisenization vary from northwest to northeast; dips range from vertical to steep to the west. More complete descriptions of the localities are available from the older literature, as referenced by Taylor (1969).

It is significant that in the South Mountain batholith, all the pegmatitic-type mineralization occurs within the New Ross-Vaughn complex. This fact adds to the other unique features of the pluton. Lithologically, the New Ross-Vaughn body is more varied than any other adamellite pod. Not only are there several textural varieties of adamellite present but there are also several minor intrusive phases as well as numerous aplite and porphyry dykes. Some of these rocks are the most highly altered lithologies of the batholith (e.g. phases in the zone of intense reddening in the northeast corner of the pluton). In addition, the geochemistry of the New Ross-Vaughn rocks indicates that they are among the most differentiated phases of the batholith. A large associated negative gravity anomaly and high rates of heat flow and heat production complete the unique picture of the complex.

These features imply that the mineralized dykes and greisen zones evolved in a specific geological environment; which, if defined and understood, would aid mineral exploration over other granitic bodies. The following discussion briefly attempts to explain the above geologic data.

III Discussion

The principal difficulty in reconciling the association of mineralization with the New Ross-Vaughn complex is to decide how the evolution of this pod differed from the evolution of the other adamellite bodies. A consideration of the significance of the large negative gravity anomaly associated with the New Ross-Vaughn body may help elucidate this problem. The cylinder of low density granitic rock causing the anomaly was probably the last major portion of the batholith to solidify. After final emplacement the batholith complex is believed to have cooled from the margins inward; therefore magma persisted longer in the central core than elsewhere in the pluton. Volatile and incompatible elements would have tended to concentrate in this region through fractional crystallization. Final autointrusion of phases rich in these elements then produced the late-stage mineralized dykes and greisen zones.

The concentration of volatiles and incompatibles in the New Ross-Vaughn complex might have been enhanced by the geometry of the batholithic intrusion. Experimental and structural studies (Grout, 1949, Ramberg, 1967, 1969; Balk, 1935) have shown that it is common for granitic plutons to be mushroom-shaped with convex upward roofs. If this were the original form of the South Mountain batholith, it seems reasonable to assume that maximum roof curvature would have been centred over the feeder conduit. Figure 8.1 demonstrates how this roof geometry could help account for the abundance of volatiles and mineral-bearing fluids in the New Ross-Vaughn pluton.

Although the plutons to the east and west of the South Mountain batholith do not have associated negative gravity anomalies on the scale of the New Ross-Vaughn body, this does not preclude the possibility of mineralizations in them. Indeed, a pegmatite carrying small amounts of argentiferous galena, malachite, azurite and some rare minerals has been found in the pluton north of Musquodoboit Harbour, Halifax Co. These plutons may be cupolas of South Mountain batholith magma which are separated from the main body at the present level of exposure by roof rocks. As the volatile- and mineral-bearing fluids tend to migrate to zones of low pressure, in some instances they might have

Figure 8.1: Schematic cross-section (after Whitney,1972) of the South Mountain batholith demonstrating how volatiles might be concentrated in the New Ross-Vaughn complex.The striped area represents the zone of vapour over saturation. The vapour saturation surface(P_1) is not fixed,but would move downward in response to decreasing temperature.

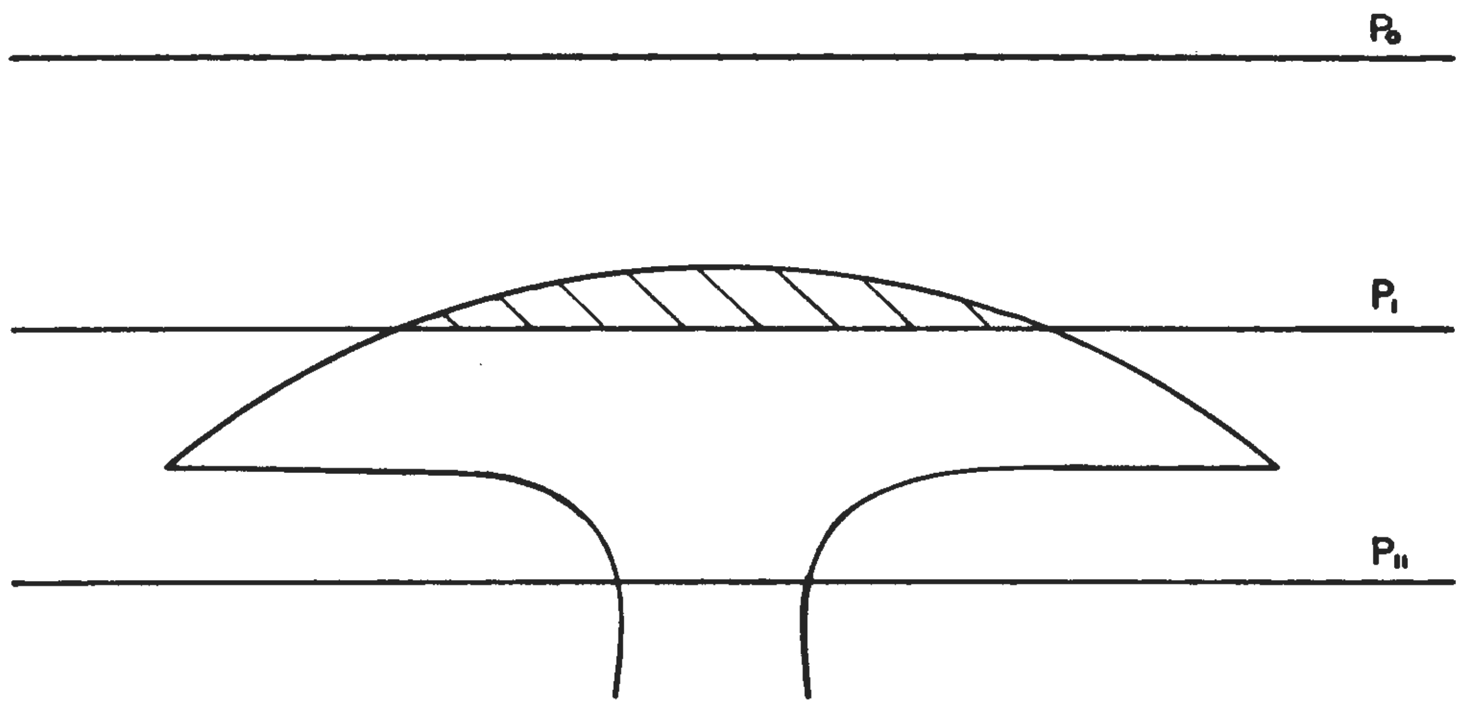


FIG. 8.1

become trapped against the roofs of the smaller plutons. In this way, communication with the central New Ross-Vaughn complex could have been effectively cut off. The other consideration is that each pluton is a separate body. In this situation each one could concentrate its own mineralizing fluids. However, the potential size of these deposits would probably be smaller than those of the New Ross-Vaughn complex.

IV Manganese Mineralization

Manganese in the South Mountain batholith occurs in the biotite granodiorites 13 km north of New Ross, Lunenburg Co. According to Weeks (1946) the one deposit occurs intermittently over a distance of 3 km in a series of NE trending en echelon veins which are probably fault controlled. The veins are lenticular and apparently not of commercial value. Pyrolusite and manganite are the principal ores present; psilomilane, hematite and limonite have also been observed (Taylor, 1969). At present, there are no available data on its origin, mode of formation or age.

A manganiferous vein has also been reported from south of Morristown, Kings Co. However, no information is currently available on the mineralogy, size or grade of this occurrence.

V Summary

The South Mountain batholith contains two types of mineral deposits. The first type, consisting of pegmatitic deposits of Sn and W or Mo, is restricted to the New Ross-Vaughn adamellite complex. These occurrences have been formed by the emplacement of volatile and incompatible element-bearing pegmatite magmas into the roof zone of the pluton. These late-stage events marked the end of the magmatic evolution of the batholith.

The second type of deposit is manganese mineralization in the biotite granodiorites. The mineralization consists of lenses of pyrolusite and manganite ore distributed along a fault zone.

Mineral Occurrences in the South Mountain Batholith*

Name of Deposit	Location	Host	Size	Minerals
Keddy molybdenum	Lake Ramsay, Lunen. Co.	aplitic granite (alaskite)	1-6 cm vein	molybdenite
Swinimer molybdenum	Leminster Hants Co.	quartz vein in Meguma metasediments	25-15 cm by 3m long	molybdenite, tourmaline
Walker molybdenum	New Russell Lunen. Co.	pegmatite and greisen		molybdenite, bornite, malachite, tourmaline, fluorine
Morley's pegmatite	New Ross Lunen Co.	pegmetite	11 m wide 1.5 km long	lithium, tungsten, beryllium, fluorine, radium and tin-bearing minerals
Mitchell tin	Lake Wallaback Lunen.Co.	pegmatite and greisenized granite	2m wide several 10's m wide	cassiterite
Rafuse tin	New Ross Lunen. Co.	2 pegmatites, aplite	6.5 m wide 1 m wide	cassiterite, gold
Rewes tin	Lake Ramsay Lunen. Co.	pegmatite segregation in alaskite	3m wide	cassiterite, ambylgonite, lepidolite, topaz, tourmaline, fluorite, monazite, beryl columbite-tanlalite, wolframite, scheelite, gummite, durangite
Russell tin	Walden Lunen Co.	pegmatite	7.5 m wide	cassiterite
Turner tin	New Ross Lunen. Co.	4 greisen and quartz veins		cassiterite, stennite, scheelite, wolframite, chalcopyrite, bornite, malachite, hematite, radioactive minerals
Dean Chapter Riddle manganese	North of New Ross, Lunen. Co.	biotite granodiorite	local ore concentration over a zone 3 km long	pyrolusite, manganite

* Compiled from Metallic Mineral Occurrences, Nova Scotia Department of Mines, 1966.

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

I Conclusions

From this study a number of conclusions concerning the age, origin, mode of formation and P,T conditions of formation of the South Mountain batholith can be made. However, it should be reiterated that these conclusions have been inferred from a limited amount of data spread over a large area. Therefore, they are preliminary conclusions only and will undoubtedly be modified by future investigations. Following the order in which events took place in the batholith, these conclusions are:

1. The South Mountain batholith magma was generated from the partial melting of lower crustal material during the folding and metamorphic events of the Acadian orogeny.
2. Heat for fusion was transferred to the lower crust from calc-alkaline magmas rising from an eastward dipping subduction zone. Those magmas are now represented by the Silurian New Canaan volcanics.
3. The Sr^{87}/Sr^{86} initial ratios suggest that the magma was not produced solely from rocks of continental origins, but rather that mantle-derived magmas played a significant role in the source of the batholith.
4. The granitic magma probably rose through the lower crust by plastic deformation of the deep crustal rocks. The batholith was ultimately emplaced into the upper crust as a mushroom-shaped body by means of fracture and stoping.
5. The high level stage of granitic invasion proceeded rather

quietly into the pre-folded and metamorphosed Lower Paleozoic sequences. Heat from the granites thermally metamorphosed the country rocks to the hornblende hornfels facies up to 2.5 km from the granite/metasediment contact.

6. The South Mountain batholith was emplaced as a single body of magma containing approximately 70% SiO_2. An average radiometric age of 370 m.y. indicates that intrusion of the batholith took place in Middle and/or Late Devonian times.

7. Biotite granodiorite was the first phase of the batholith to crystallize.

8. Five adamellitic bodies were differentiated from the granodiorites as a result of biotite and plagioclase fractionation.

9. The adamellite bodies autointruded the granodiorites and crystallized more or less sequentially from west to east. Thus the West Dalhousie and Morse Road adamellites are less differentiated than the Springfield Lake, Lake George, and New Ross-Vaughn plutons.

10. From mineralogical evidence (e.g. andalusite and rapakivi alkali feldspars) in the adamellites, it appears that crystallization began at pressures in excess of 4 kb, but terminated at pressures less than 4 kb. These mineralogical features also indicate that the adamellite magmas crystallized under approximately water saturated conditions.

11. Conclusion 10 also indicates that the adamellites differentiated from the granodiorites at high crustal levels.

Cann (1970) has shown that water saturated granitic melts do not have the ability to rise far from their place of origin. Thus, the "wet" adamellites probably did not ascend from depth but were evolved near their final emplacement level.

12. The occurrence of primary andalusite in the adamellites suggests that the work of Richardson et al. (1969) may be the most reliable estimation of aluminum silicate relations currently available, at least as regards the position of the andalusite-sillimanite boundary curve.

13. Intrusion of a series of alaskitic and leucoadamellitic dyke rocks and minor intrusive bodies marked the final stages of magmatism in the South Mountain batholith.

14. Pegmatite dykes and greisen zones containing Sn, W, Mo mineralization are found solely within the New Ross-Vaughn complex and are also associated with a negative gravity anomaly.

15. Manganese mineralization in the South Mountain is, for the most part, restricted to a fault zone in the granodiorites found north of the New Ross area.

16. As evidenced by a number of large inliers of country rock in structural conformity with the rest of the Meguma along the length of the batholith, the present level of exposure may be near the roof zone of the pluton.

II Recommendations for Future Work

The principal goals of this thesis were to stimulate interest in Nova Scotia granites by examining the South Mountain batholith and to lay the groundwork for further investigations. Within the South Mountain batholith a few of the possibilities for future studies are:

1. to complete the mapping of the batholith in the area east of Route 14 and west of the Halifax area studied by Smith (1973) and also much of the western end of the pluton remains unmapped,

2. to undertake a comprehensive investigation of the petrographic and geochemical variations within the biotite granodiorites in order to define any geographic heterogeneities in this rock unit and determine their cause (e.g. differentiation, contamination, or two or more granodioritic magmas),

3. to map one or all of the adamellite pods in detail and fully investigate the petrography and geochemistry of each in order to permit a more complete characterization of the adamellites, and understanding of the batholith as a whole,

4. to determine by radiometric means the age relations and initial Sr^{87}/Sr^{86} ratios of the various phases of the granite, in order to elucidate the intrusive sequence, the time span of emplacement and the source material(s) of the granites,

5. to study the New Ross-Vaughn complex as a means of determining the significance of the association of the mineralization, negative gravity anomaly, and high heat flow and heat production found in this pluton,

6. to investigate the geographic and mineralogical extent of hydrothermal alteration in the batholith and to determine its role in the development of the body and its significance to the Sn, W, Mo mineralization,

7. to undertake one of several possible mineralogical studies (e.g. feldspars, micas, or garnets) in order to better characterize the mineralogy of the various phases and relate the conditions of formation of the mineral suites to the petrogenesis of the batholith.

Elsewhere in Nova Scotia there is tremendous scope for research on granites. The South Mountain batholith shares the Meguma platform with some twenty other granitic plutons. Very little is known about any of these bodies and each one represents a potential research project. Moreover, the temporal, spatial, and geochemical relations among the granite bodies are also imperfectly known. On a larger, more regional scale, the relationships of the Meguma platform granites to the Devonian intrusives in Cape Breton, northern Nova Scotia and New Brunswick might be investigated. Keeping in mind the unique Appalachian geology of western Nova Scotia, it might also be instructive to consider the Nova Scotia granites in light of rocks of similar age in Europe and North Africa.

APPENDIX A: PETROGRAPHY

I Definitions of Terms Used in Petrographic Descriptions

1. Quality of outcrop:

    excellent - large outcrop with abundant fresh surfaces

    good - large to intermediate-sized outcrop with some fresh surfaces

    fair - intermediate to small outcrop with few fresh surfaces

    poor - glacial pavement or weathered outcrop with rare fresh surfaces

2. Degree of alteration:

    fresh - rock generally light grey in colour; plagioclase, alkali feldspar and biotite show minor amounts of secondary sericite, kaolinite and chlorite, respectively

    moderate - rock may be grey, pinkish or buff coloured; most plagioclases show some degree of sericitization, especially in the grain cores; alkali feldspars are generally somewhat clouded by kaolinization and may show considerable secondary muscovite; biotites may be completely chloritized or altered to muscovite

    extensive - rock is pinkish, buff or red coloured; hematization clouds both types of feldspars in addition to sericitization and kaolinization; biotites are chloritized and secondary muscovite and/or epidote may also be developed.

3. Grain size:

coarse .5 cm to 3 cm

medium .1 cm to .5 cm

fine <.1 cm

II <u>Petrographic Descriptions of Chemically Analyzed Samples</u>

M72-39: Biotite granodiorite (mode in Table 3.1)

Quality of outcrop: fair

Degree of alteration: fresh

Description: Coarse-grained, granitic (i.e. hypidiomorphic granular) assemblage of quartz, plagioclase (An_{32})[1] with oscillatory, normal and patchy zoning, alkali feldspar and biotite. Mottled by perthitic alkali feldspar phenocrysts (Or_{92})[2]. Accessory apatite, zircon (with pleochroic haloes) and opaque minerals generally associated with biotite.

M72-43B: Aplite from Greywood leucoadamellite (mode in Table 5.2)

Quality of outcrop: poor, glacial pavement

Degree of alteration: moderate

Description: Fine-medium grained, aplitic assemblage of quartz, plagioclase (An_6), alkali feldspar, muscovite

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[1] Plagioclase compositions have been determined for grain cores and thus represent the maximum An content.

[2] Alkali feldspar compositions are for host only and do not include albitic lamellae.

and chloritized biotite. Accessory andalusite, apatite and opaque minerals.

M72-50: Porphyritic adamellite from West Dalhousie adamellite (mode in Table 4.2)

Quality of outcrop: fair

Degree of alteration: fresh

Description: Medium to coarse grained, granitic assemblage of quartz, oscillatory and normally zoned plagioclase (An_{30}), alkali feldspar, biotite and muscovite. Numerous lath-shaped perthite phenocrysts (Or_{93}) with zonally arranged inclusions of plagioclase, quartz and mica. Phenocrysts often aligned and occasionally show rapakivi textures. Accessory apatite, zircon (haloed) and opaque minerals generally enclosed in biotite. Zircons ubiquitous in some grains of biotite.

M72-52: Leucoadamellite from Greywood leucoadamellite (mode in Table 5.2)

Quality of outcrop: poor

Degree of alteration: extensive

Description: Pink, medium-grained, granitic assemblage of quartz, plagioclase (An_9), alkali feldspar, biotite and muscovite. Occasional alkali feldspar phenocrysts. Biotite generally chloritized. Accessory apatite, zircon and andalusite.

M72-53: Biotite granodiorite (mode in Table 3.1)

Quality of outcrop: good

Degree of alteration: fresh

Description: Groundmass consists of coarse grained, hypidiomorphic granular quartz, plagioclase with oscillatory, normal and patchy zoning (An_{30}), alkali feldspar and biotite. Some large perthite phenocrysts (Or_{95}). Accessory apatite, zircon and opaque minerals are generally contained in the biotite.

M72-54E: Contact facies granodiorite (mode in Table 3.1).

Quality of outcrop: fair

Degree of alteration: slight

Description: Medium-coarse grained, granitic assemblage of quartz, plagioclase (An_{35}) with feldspar and biotite. Plagioclase occurs as stubby, squarish prisms up to 3 cm in length. Biotite is very abundant and contains accessory apatite, zircon (haloed) and opaque minerals.

M72-60: Biotite granodiorite (mode in Table 3.1).

Quality of outcrop: good

Degree of alteration: fresh

Description: Groundmass comprised of coarse-grained granitic quartz, plagioclase (An_{30}) with oscillatory, normal and patchy zoning, alkali feldspar and biotite. A few perthite phenocrysts. Accessory zircon (haloed), apatite and opaque minerals generally occur as inclusions in biotite.

M72-72: Biotite granodiorite (mode in Table 3.1)

Quality of outcrop: good

Degree of alteration: fresh

Description: Groundmass comprised of coarse-grained granitic quartz, plagioclase (An_{34}) with oscillatory, normal and patchy zoning, alkali feldspar and biotite. Some perthite phenocrysts (Or_{93}) which may poikilitically enclose quartz, plagioclase and biotite inclusions. Accessory apatite and zircon (haloed) generally contained in biotite.

M72-82: Porphyritic adamellite from West Dalhousie adamellite (mode in Table 4.2)

Quality of outcrop: good

Degree of alteration: fresh

Description: Groundmass consists of medium to coarse grained assemblage of quartz, oscillatory and normally zoned plagioclase (An_{30}), alkali feldspar, biotite and muscovite. Numerous, lath-shaped perthite phenocrysts which often contain abundant concentrically arranged inclusions of plagioclase, quartz and biotite. Phenocrysts are often aligned and some show rapakivi textures. Biotite contains abundant haloed zircons as well as apatite and opaque minerals. Zircons occasionally zonally arranged.

M72-86: Biotite granodiorite (mode in Table 3.1)

Quality of outcrop: good

Degree of alteration: fresh

Description: Medium to coarse grained, granitic assemblage of quartz, plagioclase (An_{34}) with oscillatory, normal and patchy zoning, alkali feldspar and biotite. Some perthite phenocrysts (Or_{94}). Accessory apatite, zircon (haloed) and opaque minerals generally contained in biotite.

M72-100A: Aplite (mode in Table 5.2)

Description of outcrop: good

Degree of alteration: extensive

Description: Fine-medium grained, aplitic assemblage of quartz, plagioclase (An_7), alkali feldspar, muscovite and chloritized biotite. Feldspars pinkish or reddish due to occluded hematite.

M72-102: Adamellite from Lake George adamellite (mode in Table 4.2)

Quality of outcrop: good

Degree of alteration: moderate-extensive

Description: Groundmass comprised of medium to coarse grained, granitic quartz, oscillatory and normally zoned plagioclase (An_{28}), alkali feldspar and muscovite. Some plagioclase grains completely hematized. Numerous lath-shaped, pink perthite phenocrysts which often contain abundant concentrically arranged inclusions of plagioclase, quartz and biotite. Phenocrysts often aligned. Biotite contains ubiquitous zonally arranged zircons (haloed) as well as apatite and opaque minerals. Rare accessory andalusite mantled in muscovite.

M72-114: Porphyritic adamellite from New Ross-Vaughn complex (mode in Table 4.2)

Quality of outcrop: good

Degree of alteration: moderate

Description: Groundmass comprised of medium-coarse grained, granitic quartz, oscillatory and normally zoned plagioclase (An_{30}), alkali feldspar, biotite and muscovite. Abundant lath-shaped perthite phenocrysts (Or_{91}), with common quartz and plagioclase. Some biotites crowded with haloed zircon inclusions. Accessory apatite also associated with biotite.

The calcic plagioclases are generally coarse grained and, except for their clear albitic rims, completely reddened by hematization whereas the albitic plagioclases are medium grained and generally appear unaltered. Numerous pink, lath-shaped perthite phenocrysts with common zonally arranged inclusions of plagioclase, quartz and mica. Phenocrysts commonly aligned. Biotite often crowded with accessory zircon (haloed). Apatite and opaque minerals also present.

M72-123: Porphyry (mode in Table 5.2)

Quality of outcrop: excellent

Degree of alteration: moderate

Description: Groundmass comprised of fine-medium grained, aplitic quartz, plagioclase (An_6), alkali feldspar, muscovite and biotite. Medium to coarse grained phenocrysts of perthitic alkali feldspar (Or_{92}), plagioclase (An_{24}) and quartz. Perthite phenocrysts contain quartz, plagioclase and biotite inclusions. Accessory apatite and zircon (haloed) generally associated with biotite.

M72-124: Biotite granodiorite (mode in Table 3.1)

Quality of outcrop: excellent

Degree of alteration: fresh

Description: Medium to coarse grained, granitic assemblage of quartz, plagioclase (An_{34}) with oscillatory, normal and patchy zoning, alkali feldspar and biotite. Some alkali feldspar phenocrysts (Or_{93}). Accessory apatite, zircon (haloed) and opaque minerals generally enclosed in biotite. Rare accessorv subhedral garnet.

M72-116A: Aplite (mode in Table 5.2)

Quality of outcrop: excellent

Degree of alteration: moderate-extensive

Description: Fine-medium grained, aplitic assemblage of quartz, plagioclase (An_5), alkali feldspar, muscovite and chloritized biotite. Feldspars pinkish or reddish from occluded hematite dust. Rare accessory apatite.

M72-119: "Fresh" adamellite from New Ross-Vaughn complex (mode in Table 4.2)

Quality of outcrop: excellent

Degree of alteration: moderate

Description: Medium-coarse grained, granitic assemblage of quartz, oscillatory and normally zoned plagioclase

(An_{28}), alkali feldspar, biotite and muscovite. Occasional perthite phenocrysts (Or_{94}). Apatite and haloed zircons often included in biotite. Andalusite mantled by muscovite.

M72-121: Porphyritic adamellite from New Ross-Vaughn complex (mode in Table 4.2)

Quality of outcrop: excellent

Degree of alteration: extensive

Description: Groundmass consists of medium to coarse grained, granitic quartz, albitic plagioclase (An_6), plagioclase (oligoclase/andesine), alkali feldspar, biotite and muscovite.

M72-127: Transitional biotite granodiorite (mode in Table 3.1)

Quality of outcrop: poor

Degree of alteration: moderate

Description: Medium to coarse grained, granitic assemblage of quartz, oscillatory and normally zoned plagioclase (oligoclase/andesine), alkali feldspar and biotite. Only occasional alkali feldspar phenocrysts (Or_{96}). Accessory apatite, zircon (haloed) and opaque minerals associated with biotite.

M72-137: Biotite granodiorite (mode in Table 3.1)

Quality of outcrop: excellent

Degree of alteration: fresh

Description: Coarse grained, granitic assemblage of quartz, plagioclase (An_{33}) with oscillatory, normal and patchy zoning, alkali feldspar and biotite. Some perthite phenocrysts (Or_{94}) with plagioclase, quartz and biotite inclusions. Accessory apatite, zircon (haloed) and opaque minerals associated with biotite.

M72-156: Alaskite from Card Lake alaskite (mode in Table 5.2)

Quality of outcrop: fair

Degree of alteration: extensive

Description: Fine-medium grained, aplitic assemblage of quartz, plagioclase (An_4), alkali feldspar, muscovite, and biotite. Feldspars pinkish or reddish from occluded hematite dust. Biotites chloritized. Accessory apatite.

M72-160: Porphyry (mode in Table 5.2)

Qualith of outcrop: fair

Degree of alteration: moderate

Description: Groundmass comprised of fine to medium grained, aplitic quartz, albitic plagioclase (An_8), alkali feldspar, biotite and muscovite. Medium to coarse grained phenocrysts of alkali feldspar (Or_{98}), quartz, plagioclase (oligoclase/andesine) and rarely biotite. Both alkali feldspar and plagioclase phenocrysts commonly contain fine, zonally arranged quartz inclusions. Accessory apatite, zircon (haloed) and opaque minerals associated with biotite.

M72-161: Medium grained adamellite from New Ross-Vaughn complex (mode in Table 4.2)

Quality of outcrop: excellent

Degree of alteration: moderate

Description: Medium-grained, granitic assemblage of quartz, oscillatory and normally zoned plagioclase (An_{34}), alkali feldspar, biotite and muscovite. Occasional perthite pherocrysts (Or_{96}) with common plagioclase, quartz and mica inclusions. Some rapakivi textures. Accessory zircon (haloed) and apatite contained in biotite. Zircons zonally arranged in some grains. Andalusite enveloped in muscovite.

M72-166: Porphyritic adamellite from New Ross-Vaughn complex (mode in Table 4.2)

Quality of outcrop: good

Degree of alteration: moderate to extensive

Description: Medium to coarse grained, granitic assemblage of quartz, oscillatory and normally zoned plagioclase (oligoclase/andesine), alkali feldspar, biotite and muscovite. Some plagioclase grains completely hematized. Perthite phenocrysts (Or_{92}) with common plagioclase, quartz and mica inclusions. Occasional rapakivi textures. Accessory zircon (haloed) and opaque minerals contained in biotite. In places zircons are zonally arranged. Andalusite associated with muscovite.

M72-172: Biotite granodiorite (mode in Table 3.1)

Quality of outcrop: fair

Degree of alteration: fresh

Description: Coarse grained, granitic assemblage of quartz, plagioclase (sodic andesine?) with oscillatory, normal and patchy zoning, alkali feldspar and biotite. Only occasional perthite phenocrysts which contain abundant plagioclase and biotite inclusions. Accessory apatite, zircon (haloed) and opaque minerals generally associated with biotite.

M72-176: Porphyritic adamellite from New Ross-Vaughn complex (mode in Table 4.2)

Quality of outcrop: excellent

Degree of alteration: moderate-extensive

Description: Medium to coarse grained, granitic assemblage of quartz, oscillatory and normally zoned plagioclase (An_{28}), alkali feldspar, biotite and muscovite. Occasional pinkish perthite phenocrysts. Alkali feldspars may show concentrically arranged inclusions of plagioclase, quartz and mica and a few grains have rapakivi textures. Accessory zircon (haloed), apatite and opaque minerals associated with biotite.

M72-182: Aplite (mode in Table 5.2)

Quality of outcrop: poor

Degree of alteration: moderate

Description: Fine-medium grained, aplitic assemblage of quartz, plagioclase (An_9), alkali feldspar, muscovite and biotite. Biotite is generally chloritized. Rare accessory apatite.

M72-189: Adamellite from Springfield Lake adamellite (mode in Table 4.2)

Quality of outcrop: fair

Degree of alteration: moderate-extensive

Description: Generally medium grained, granitic assemblage of quartz, albitic plagioclase (An_7), calcic plagioclase (An_{32}) with oscillatory and normal zoning, alkali feldspar, biotite and muscovite. Calcic plagioclase is generally coarser in grain size than the albitic plagioclase and also more extensively altered. Occasional perthite phenocrysts (Or_{96}) contain common plagioclase, quartz and mica inclusions. Accessory apatite, zircon (haloed) and opaque minerals generally contained in biotite.

M72-192: Biotite granodiorite (mode in Table 3.1)

Quality of outcrop: excellent

Degree of alteration: fresh

Description: Medium to coarse grained, granitic assemblage of quartz, plagioclase (An_{31}) with oscillatory, normal and patchy zoning, interstitial alkali feldspar and biotite. Perthite phenocrysts (Or_{94}) contain plagioclase, biotite and quartz inclusions. Accessory apatite zircon (haloed) and opaque minerals generally associated with biotite.

M72-197: Leucoadamellite from Lewis Lake leucoadamellite (mode in Table 5.2)

Quality of outcrop: fair

Degree of alteration: extensive

Description: Fine-medium grained, aplitic assemblage of quartz, plagioclase (An_6), alkali feldspar and muscovite. Accessory topaz and biotite.

M72-198: Porphyry from Morse Road adamellite (mode in Table 4.2)

Quality of outcrop: excellent

Degree of alteration: fresh

Description: Groundmass consists of medium grained, granitic quartz, oscillatory and normally zoned plagioclase, alkali feldspar, biotite and muscovite. Phenocrysts of perthitic alkali feldspar (Or_{94}), plagioclase (An_{32}) with oscillatory and normal zoning, quartz and biotite. Accessory apatite, zircon and opaque minerals generally associated with biotite. Tourmaline present.

Plate 1. M72-83 (X31.25, crossed polars). Augen granodiorite. Oriented biotites wrapped around plagioclase auge.

Plate II. M72-102 (X31.25, crossed polars). Porphyritic adamellite. Concentrically arranged quartz and plagioclase inclusions in perthitic alkali feldspar phenocryst.

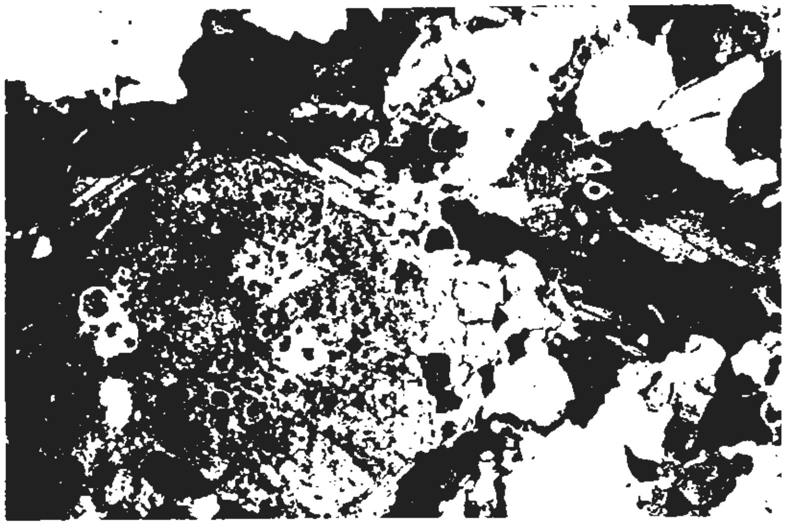
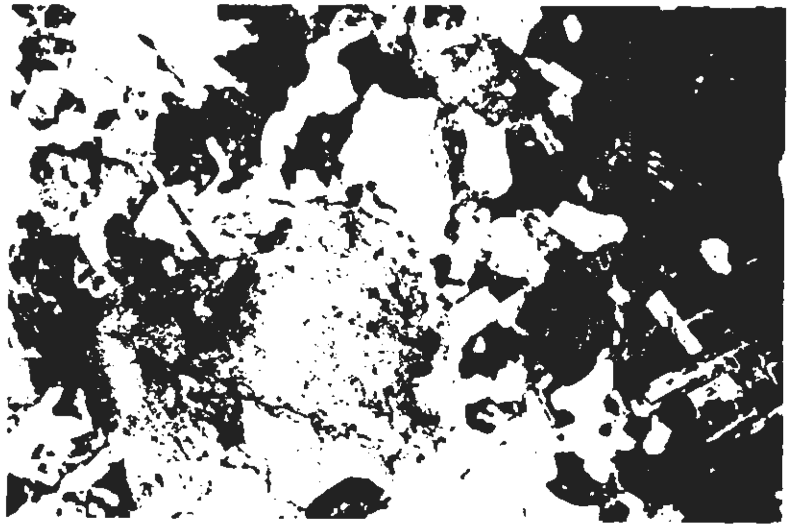


Plate III. M72-160 (X31.25, crossed polars). Porphyry: Quartz phenocryst in aplitic groundmass.

Plate IV. M72-160 (X31.25, crossed polars). Porphyry: Plagioclase (albitic) phenocryst with concentrically arranged quartz inclusions.



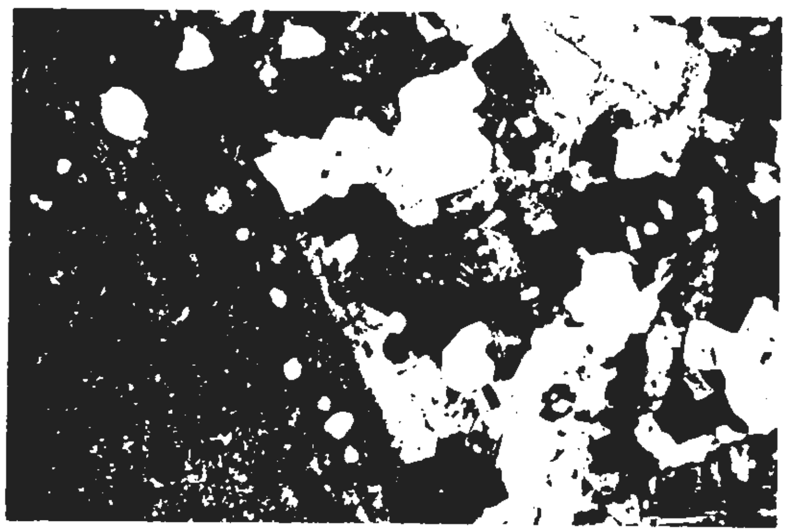
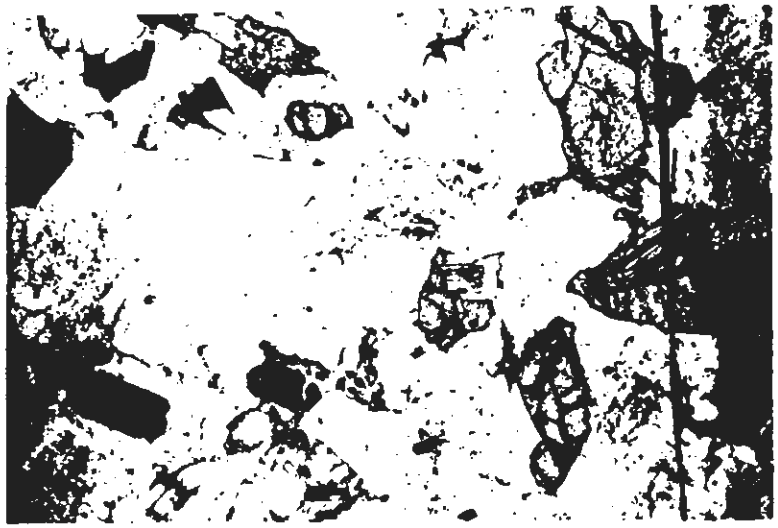


Plate V. M72-135A (X31.25, plane polarized light). Xenolith from biotite granodiorite. Garnets (almandine?) in a recrystallized xenolith.

Plate VI. M72-76A (X31.25, crossed polars). Xenolith from biotite granodiorite. Microcline porphyroblast poikilitically enclosing quartz and plagioclase.



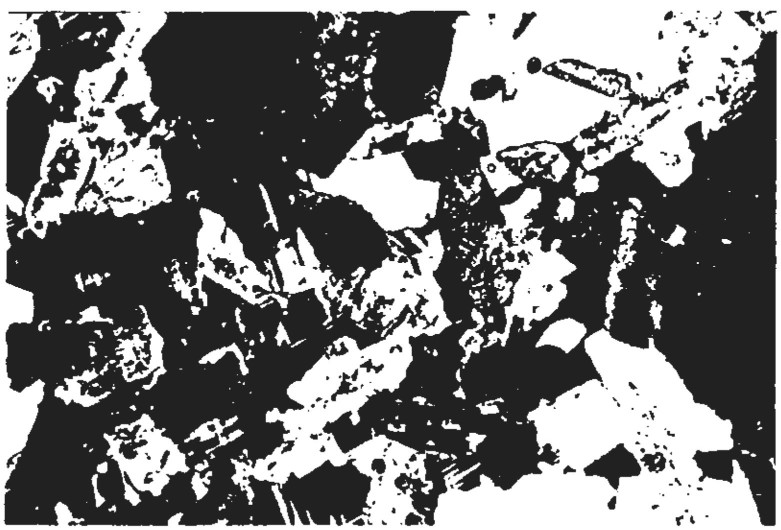
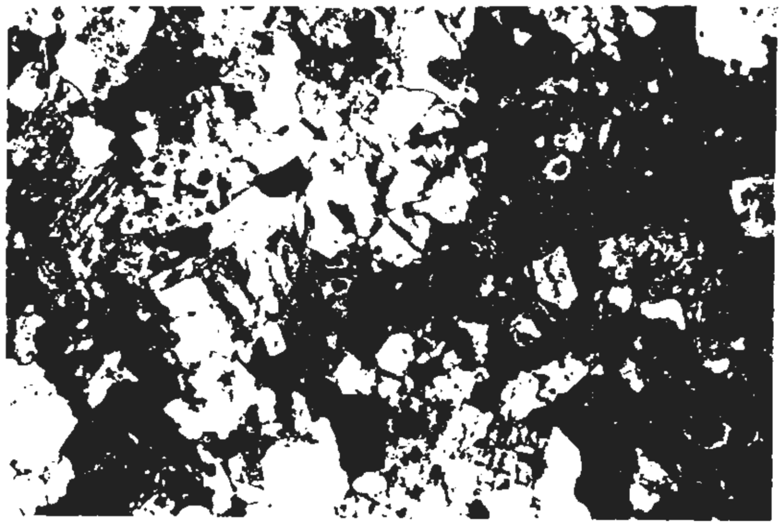


Plate VII. M72-197: (X31.25, crossed polars). Leuco-adamellite: Topaz in aplitic groundmass.

Plate VIII. M72-43B: (X31.25, crossed polars). Leuco-adamellite: Andalusite grains mantled in muscovite.



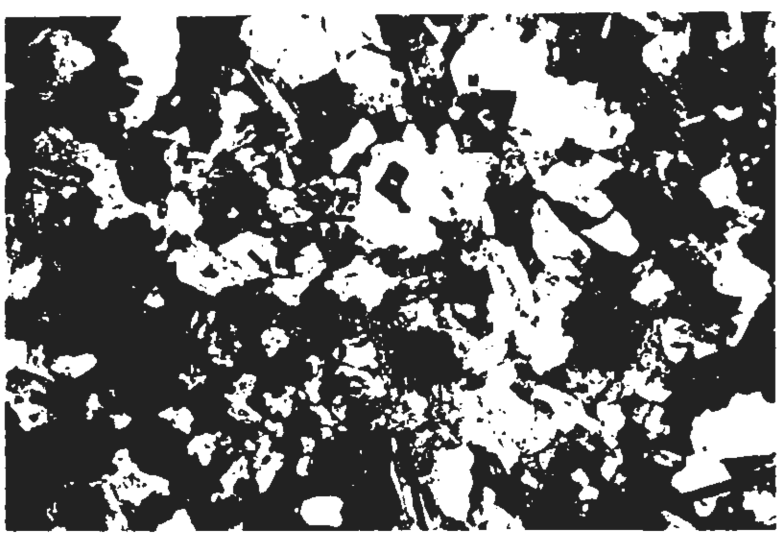
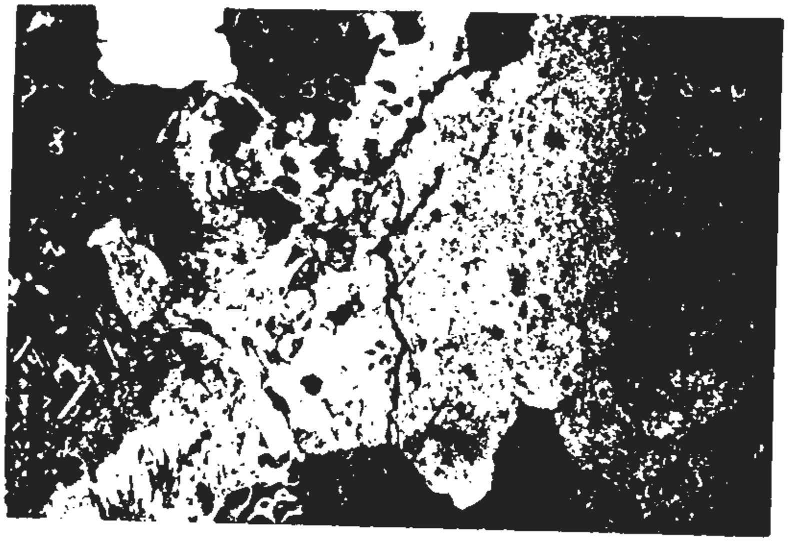


Plate IX. M72-119 (X31.25, crossed polars). Adamellite: Andalusite and muscovite interstitial with quartz and plagioclase.

Plate X. M72-49 (X31.25, crossed polars). Porphyritic adamellite: Rapakivi alkali feldspar.



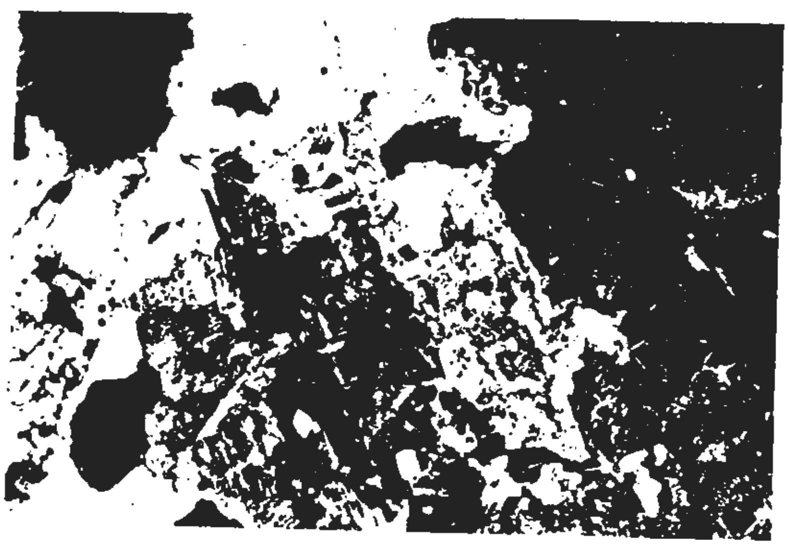


Plate XI. M72-53 (X31.25, crossed polars). Biotite granodiorite. Plagioclase (An_{30}) exhibiting oscillatory and normal zoning.

Plate XII. M72-124 (X31.25, crossed polars). Biotite granodiorite. Perthitic alkali feldspar showing interstitial relations with sericitized plagioclase.

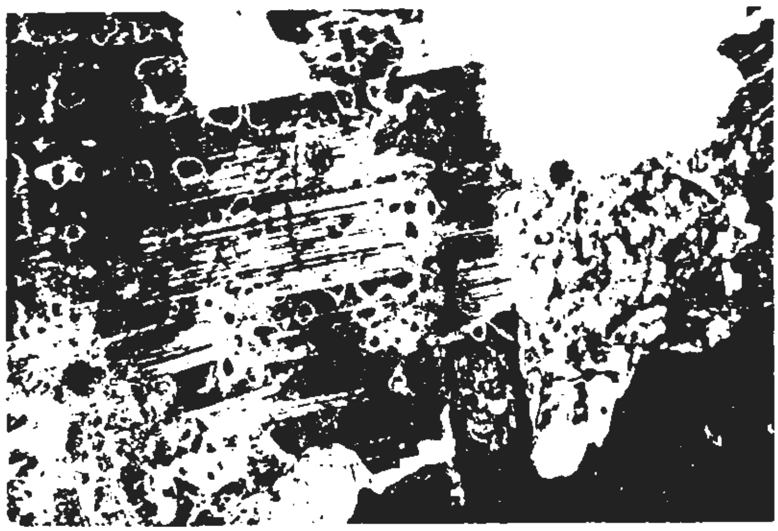
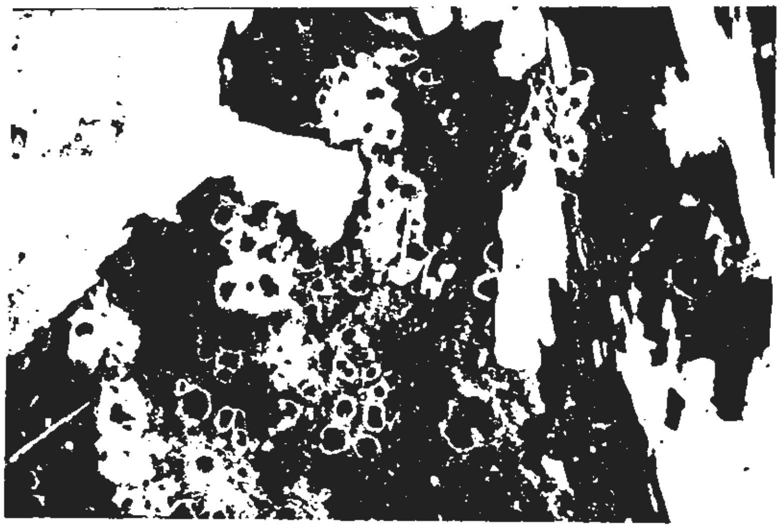


Plate XIII. M72-121 (X31.25, plane polarized light). Porphyritic adamellite: Concentrically arranged zircons in biotite.



APPENDIX B: ANALYTICAL METHODS

I. Modal analyses

Modal analyses were performed on thin sections and slabbed sections. Thin section analyses were carried out according to the method described by Chayes (1956). Precision was maintained at a minimum of $\sqrt{\overline{\nabla}_p}$ (the square root of the average precision variance) = 2.45%. Coarse-grained rocks were counted in slabbed section. Sections were prepared and counted according to the method described by Lyons (1971). Precision, according to Lyons (1971), compares favourably with the counting precision determined by Chayes and Fairbairn (1951).

II. Chemical analyses

a. Sample preparation:

Samples were first fragmented into fist-sized pieces using a Cutrock. Weathered surfaces were trimmed off by means of a diamond saw. Pieces were blown free of dust with compressed air and further reduced by a Chipmunck jaw crusher equipped with hardened steel crushing plates. At this point splits were made on the samples in order to obtain a representative few hundred grams of sample. The splitter consisted of a large container, which had been divided into four equal compartments, set on a turntable. The samples were fed into the rotating container by means of a funnel. One-quarter of the samples was retained for final grinding.

Samples were ground to -100 mesh size in a Scintrex 300 Shatterbox using the hardened steel mortar. The resulting powders were stored in air-tight glass jars while awaiting further processing.

b. Analytical Techniques:

1. X-ray flourescence

Seven major elements (Si, Ti, Al, Fe_{Total}, Ca, K, P) and seven trace elements (Rb, Sr, Ba, Zr, Zn, Ni, Cr) were determined by X-ray flourescence of discs pressed from rock powders using a Phillips 1220-C computerized spectrometer, courtesy of Dr. D. Strong, Department of Geology, Memorial. In the case of the major elements, the samples were first used before being pressed into discs. This procedure is as follows:

1. 0.7500 g of rock powder + 0.7500 g of La_2O_3 + 6.00 g of $Li_2B_4O_7$ were carefully weighed out, mixed together and placed in a graphite crucible.
2. A dozen crucibles per run were put in a muffle furnace preheated to 1,000°C and left to fuse for 30-35 minutes.
3. After fusion the resulting glass beads were cooled and put in clean glass jars.
4. The weight of each bead was readjusted to exactly 7.500 g with dried $Li_2B_4O_7$, compensating for weight lost during fusion and thus giving an exact dilution.
5. Each bead plus the $Li_2B_4O_7$ was put in a tungsten carbide ball mill vial, cracked with a steel cylinder, and then crushed in the ball mill to -100 mesh.

6. The powder was then put in bottles and dried overnight at 110°C. These powders (in the case of the trace element analyses the unfused powders) were made into discs in the following manner:

1. 1.5 g of rock powder was thoroughly mixed with two to three drops of N-30-88 Novial binding agent until the colour was uniform.
2. Using boric acid backing, this powder was pressed into a disc for one minute at 15 tons per square inch.

Precisions and accuracies of this method are given in Tables B.1 and B.2.

2. Atomic Absorption:

Five major elements (Al, Mg, Mn, Na, K) were analyzed by means of a Perkin-Elmer 403 Atomic Absorption Spectrometer. Magnesium, Mn, Na and K were determined using an acetylene-air flame; Al by a nitrous oxide-air flame. Solutions for analysis were prepared as follows:

1. 0.2000 g of sample powder was dissolved in 5 ml of $HClO_4$ and 25 ml of HF and the solution was evaporated nearly to dryness on a sand bath.
2. Five ml $HClO_4$ was added and the solution again evaporated almost to dryness.
3. Five ml $HClO_4$ and 50 ml H_2O were added and the solution was heated on a water lath for 1 hour, cooled, then diluted to 500 ml.
4. Standards were prepared by diluting 1000 ppm standard solutions of the elements to be analyzed.

5. Standard granodiorite JG-1 (split 6) was also run as an independent check on the precision and accuracy of the analyses.

Precision and accuracies determined for this standard are given in Table B.1.

3. Neutron activation:

Fast neutron activation analysis was employed to check the silica contents of 32 samples. The method used is similar to that described by Volborth and Vincent (1967) for oxygen, except that the 1.78 MeV peak of aluminum-28 was counted. Four runs using irradiation and counting times of 30 seconds and 100 seconds respectively were done for each standard-sample pair in order to accumulate 106 counts per sample. Corrections were made for phosphorus and iron.

4. Gravimetric

Ferrous iron was determined volumetrically using the method recommended by Volborth (1969), utilizing the inverted funnel into which CO_2 gas is led to prevent oxidation of the sample. Analyses were performed in duplicate.

Plus water was determined by the Penfield tube method described by Volborth (1969), using anhydrous sodium tungstate as flux. Samples were dried at 110°C for 24 hours before conducting the analyses.

Table B.1

Precisions and Accuracies of analytical methods for major elements

Element	Analytical Method	Accepted Value	Std. Mean	Range	Std. Dev.	Accur. (%)
SiO_2	XRF	76.58	77.4	6.8	2.15	± 1.07
		72.24	72.47 (72.74, 73.14, 71.52)	1.6	.84	± 3.
	NA	67.27	67.20	-	-	-
		75.80	76.31	-	-	-
TiO_2	XRF	0.17	0.17	.08	.03	-
Al_2O_3	XRF	12.28	12.6	1.6	.53	± 2.6
	AA	14.21	14.04	.30	.14	± 1.2
$Fe_2O_{3\,T}$	XRF	1.15	1.15	.21	.06	-
MnO	AA	0.06	0.07	.01	.006	±14.7
MgO	AA	0.73	0.74	.01	.006	± 1.4
CaO	XRF	0.87	0.92	.25	.07	± 5.7
Na_2O	AA	3.39	3.37	.05	.02	± 0.6
K_2O	XRF	1.73	1.75	.08	.03	± 1.2
	AA*	3.96	3.96	.08	.04	-
P_2O_5	XRF	0.16	0.15	.08	.04	± 6.2

* on the basis of three runs; including the fourth run

			3.91	.23	.10	± 1.3

Final major element values were generally the result of averaging the values determined from the various analytical methods. In some instances, however, values that were markedly higher or lower than the other determinations on the same element were deleted from the average.

Table B.2

Precision and Accuracy for trace element analyses

Precision

ELEMENT	RANGE	MEAN	S. DEV.
Zr	33	68	10
Sr	21	138	9
Rb	8	106	3
Zn	9	37	3
Ba	197	755	74
Ni Cr	not available (NA)		
Sn	no data available		

Accuracy

ELEMENT	RANGE(ppm)	S. DEV.	NO. STDS.
Zr	490	13	16
Sr	784	18	19
Rb	245	6	23
Zn	161	12	24
Ba	1,803	33	18

1σ accuracy

Ni	9 ppm
Cr	19 ppm
Sn	NA

Table B.3

Precision and Accuracy of microprobe analyses

Element	Accepted Value of Standard		Mean	Range	Standard Deviation	Accuracy (%)
SiO_2	KK	40.19	40.66	.12	.05	± 1.1*
Al_2O_3	KK	13.83	14.24	.17	.07	± 0.1°
Na_2O	Albite	11.83	2.63	.10	.04	± 3.54
K_2O	Hohenfels Sanidine	12.10%	2.11	.02	.009	± 0.47

* at 50% level

° at 13% level

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