PETROGRAPHY, GEOCHEMISTRY AND GEOCHRONOLOGY

OF THE

COE HILL GRANITE, HASTINGS COUNTY, ONTARIO

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COE HILL GRANITE, HASTINGS COUNTY, ONTARIO

by

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ABSTRACT

A detailed petrographic, geochemical and strontium isotope study of the rocks representing the variations observed across the Coe Hill granite, Grenville Province, southeastern Ontario provides the basis for the determination of the age and possible origin of this pluton. This study also provides insight into the relationships between similar granitoid plutons in the immediate vicinity.

The Coe Hill granite is a medium to coarse grained hypidiomorphic to allotriomorphic, leucocratic quartz monzonite with subordiante isolated inclusions of dioritic and gabbroic gneiss. Variations upon this otherwise homogeneous granitoid occur in discordant aplite dykes, assimilating mafic xenoliths and along brecciated contact boundaries.

Generally the rocks of this pluton are more basic than the average for similar granitoids in the area (12.4% vs. 6.0% mafics) as observed in both thin section and major element oxide diagrams. Besides this trend major element diagrams have uniform distributions. A Rb-Sr isochron was determined for the rocks of the pluton proper which gave an age representative of the emplacement of these rocks (t = 1063 ± 21 M.a.; R_i = 0.7040 ± 5). Trace element Rb shows a value similar to the norm for granitoids yet is enriched in comparison to values

acquired from similar granitoids in the area (144 ppm vs. 63 ppm).

Through a synthesis of the available data, and that which was acquired from this study on the Coe Hill granite, a comparison with the available data on the Loon Lake quartz monzonite can be made. This comparison illustrates a great deal of strikingly similar trends which have been taken to represent a lower crustal, or upper mantle origin, cogenetic relationship between these two granitoids.

ACKNOWLEDGEMENTS

I wish to express my appreciation to Dr. D.M. Shaw who provided valuable guidance, assistance and encouragement throughout this study. Special thanks also go to Larry Heaman for the great deal of time spent in the instruction of the arduous procedure required for solid source mass spectrometric analysis, the use of unpublished trace element data, for introducing me to the geology of this portion of the Grenville Province and for the interesting discussions concerning the problems of this area. Technicians O. Mudroch, J. Whorwood and L. Zwicker are thanked for their instruction on the use of analytical equipment, photography and preparation of thin sections, respectively. I am especially grateful to Linda Hillier for the deciphering and typing of this dissertation.

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INTRODUCTION

1.1 PURPOSE OF THE STUDY

The southeastern Ontario segment of the Grenville Province of the Canadian Shield includes a number of small granitoid plutons intruding the older metasediments and metavolcanics of this region. A number of studies (Hewitt, 1956; Saha, 1959; Macintyre et al., 1967; Silver and Lumbers, 1968; Heaman, 1980; and others) have been made on many of these granitoid plutons in attempts to elucidate the relative ages, origins and the relationships between these intrusions and the events of Grenville history.

This study on the Coe Hill granite is significant in that its relationship with respect to the Methuen granite (Hewitt, 1960), to the south (Fig. 1.3) and the well studied Loon Lake pluton (Saha, 1959; Shaw, 1962; Dostal, 1973; Shieh et al., 1976; and, Heaman, 1980), to the west (Fig. 1.3), along with its position in the events of the Grenville orogeny, is unknown.

The purpose of this study is to determine the age of the Coe Hill granite, investigate its origin and compare it with the Loon Lake pluton and the Methuen granite. In order to make these collations the study will focus on the determination of petrographic, geochemical and geochronological relationships between the Coe Hill granite and these other granitoid intrusions.

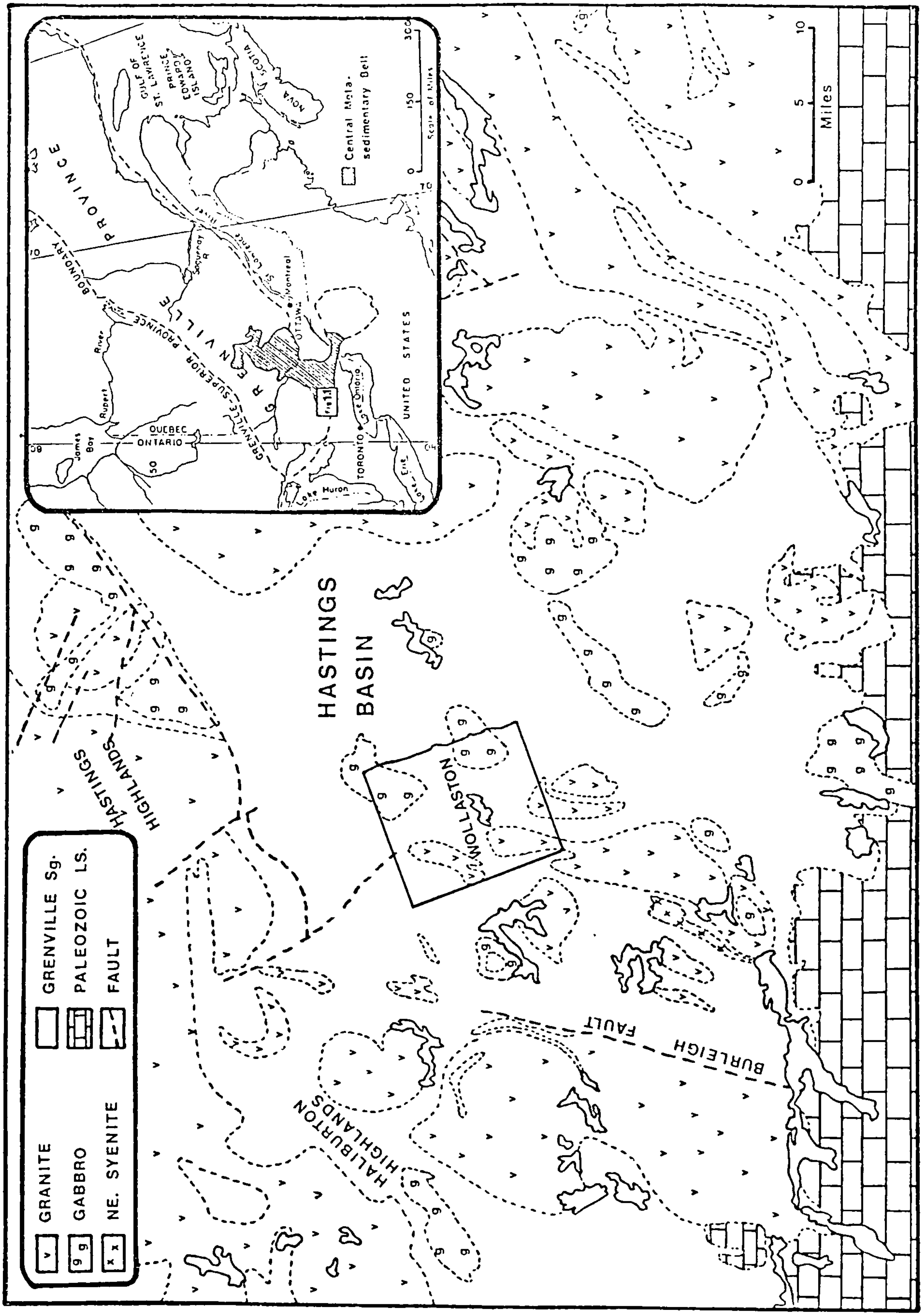
1.2 REGIONAL GEOLOGY

The Precambrian rocks of the southeastern Ontario Central Metasedimentary Belt (Fig. 1.1) are an assemblage of some of the largest and thickest metasedimentary and metavolcanic rocks in the Grenville Province (Lumbers, 1967a). Lumbers has partitioned this 400 km northeast-southwest trending, southeastern Ontario to easternQuebec (Fig. 1.1), remnant into two major stratigraphic subdivisions. These subidivision are: 1) The Hermon group of predominately mafic and some andesitic metavolcanics and metasediments (thought to represent a eugeosynclinal assemblage); and, 2) The Mayo group, a thick sequence of thin-bedded carbonate metasediments with minor interbedded calc-metasandstones, metasiltstones, metagrewackes, and, possibly some minor volcanics. The Mayo group of metasediments interfinger with all but the lowest Hermon group metavolcanics. Lumbers (1967a) interpreted the intercalation of these formations to be a result of Mayo group marine basin, or trough sediments being deposited simultaneously with Hermon submarine volcanics.

The region has been further subdivided into several structural-stratigraphic units, these being the Haliburton and Hastings Highlands and the Hastings Basin (Fig. 1.1). Shaw (1962), Chesworth (1971), Hewitt (1956) and Davidson et al. (1979) have observed that subdivisions may be made by the presence of mantled gneiss domes and granitoid migmatites, generally showing a high metamorphic grade (upper amphibolite to granulite facies), and complex structural and stratigraphic relationships, in the Highlands. The Hastings Basin has a lower metamorphic grade, migmatites are less well developed and the stratigraphic relationships are more easily defined. These two units are divided by a major fault zone roughly trending northeast-southwest and north-south (Fig. 1.1).

Wollaston Township lies in the southeast portion of the Central Metasedimentary Belt and is totally within the Hastings Basin structural subdivision. Wollaston Township consists of Mayo group metasediments and metavolcanics intruded by basic and felsic plutons of varying age. Hermon group metavolcanics and metasediments outcrop further to the north and south (Lumbers, 1967; Hewitt, 1956).

Structurally the region consists of a main folding sequence, with fold axes trending northeast-southwest, and a strongly developed crossfolding, with fold axes trending northwest-southeast (Hewitt, 1962; Shaw, 1962). Shaw (1962) has constructed a generalized geologic and structural map of Chandos and Wollaston Townships which illustrates a series of antiformal and synformal folds as well as dome and basin



MODIFIED AFTER HEWITT (1956) and DOSTAL (1973)

FIG.1.1

structures. This deformation may be attributed to metamorphism during the Grenville orogeny.

1.3 PREVIOUS WORK

1.3.1 General

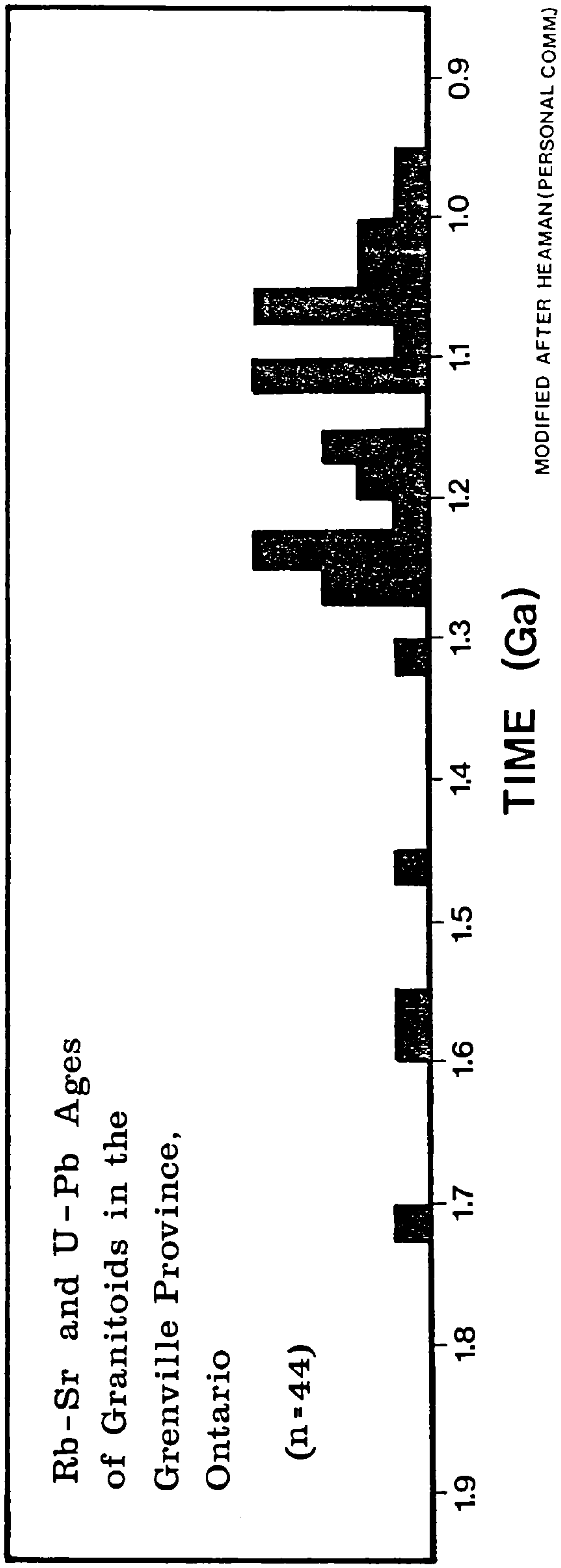
The earliest recognition of the Grenville series of metasediments was by Sr. William Logan near the town of Grenville in Quebec. Subsequent reports by Logan, Vennor, MacFarlane and Selwyn, prior to 1900, initiated the correlation of the southeastern Ontario metasediments with those of the Grenville Province in Quebec (Hewitt, 1956). In 1910, Adams and Barlow concluded a very comprehensive report and mapping project of stratigraphic relationships in the Haliburton-Bancroft area, including Wollaston Township (Hewitt, 1956). Metallic mineral exploration and aeromagnetic surveys were conducted within Wollaston Township between 1930 and 1951. Saha (1959) undertook a detailed study of the Wollaston pluton and some surrounding granitoid plutons in order to clarify the problem of emplacement of these bodies. Lumbers (1967a) completed his Ph.D. study on the regional geology of the Bancroft-Madoc area. That study contradicted Hewitt's earlier claims about some stratigraphic relationships in the area.

Other work on the Coe Hill granite is restricted to an Ontario Department of Mines report by Hewitt (1962) in which he gives a short summary chapter along with modal analyses of four samples from the granite, some oxygen isotope work by Shieh et al. (1976) and some unpublished U-Th work by T. Wu at the University of Western Ontario.

1.3.2 Geochronological

Geochronological studies have been made in the Hastings Basin and the Haliburton and Hastings Highlands regions since the early 1900s. One of the earliest published studies, by Silver and Lumbers (1965), on U-Pb systems in zircons (using old decay constants) illustrated the presence of two and possibly three periods of plutonic activity within this region. These events occurred at: 1) 1250 ± 25 m.y.; 2) 1125 ± 25 m.y.; and, possibly a third event at 1050 ± 20 m.y. A later study by Macintyre, York and Moorehouse (1967), using the K-Sr method of dating, gave ages of as much as 150 m.y. younger than those acquired from Rb-Sr whole rock and U-Pb analyses, but still indicated episodic plutonic events. Macintyre et al. attributed this 150 m.y. deviation in ages to a long cooling post metamorphic episode, or possibly due to a later heating, at approximately 900 m.y., that disturbed the K-Ar system and yet was not able to disturb the U-Pb or Rb-Sr systems. Baer (1981, p. 129) reported that "most authors have assumed that isostatic re-equilibration and erosion following orogenic activity could explain

Figure 1.2 Histogram of Rb-Sr and U-Pb ages in granitoids of the Grenville Province in southeastern Ontario.


Rb-Sr and U-Pb Ages
of Granitoids in the
Grenville Province,
Ontario
(n=44)
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
TIME (Ga)
MODIFIED AFTER HEAMAN (PERSONAL COMM.)

a 150 m.y. time-lag between Rb-Sr whole rock dates and K-Ar dates." Heaman (pers. commun.) has constructed a histogram from a compilation of all the most up-to-date Rb-Sr whole rock and U-Pb zircon geochronological studies on granitoids which summarizes the work performed in this region (Fig. 1.2). This histogram suggests the existence of three and possibly a fourth episode of plutonic activity in this region. The three peaks in the histogram, occur at 1250 m.y., 1120 m.y. and 1060 m.y. while a possible fourth episode occurs at 1180 m.y.

1.4 DESCRIPTION OF THE STUDY AREA

1.4.1 Location and Accessibility

The Coe Hill granite is located in the southwest corner of Wollaston Township (Fig. 1.3) in Hastings County, approximately 16 km south of Bancroft, Ontario (Map sheet 2020 - Ontario Department of Mines). The town of Coe Hill (located at the geographical centre of Wollaston Township) is approximately 4 km from the northern boundary of the pluton.

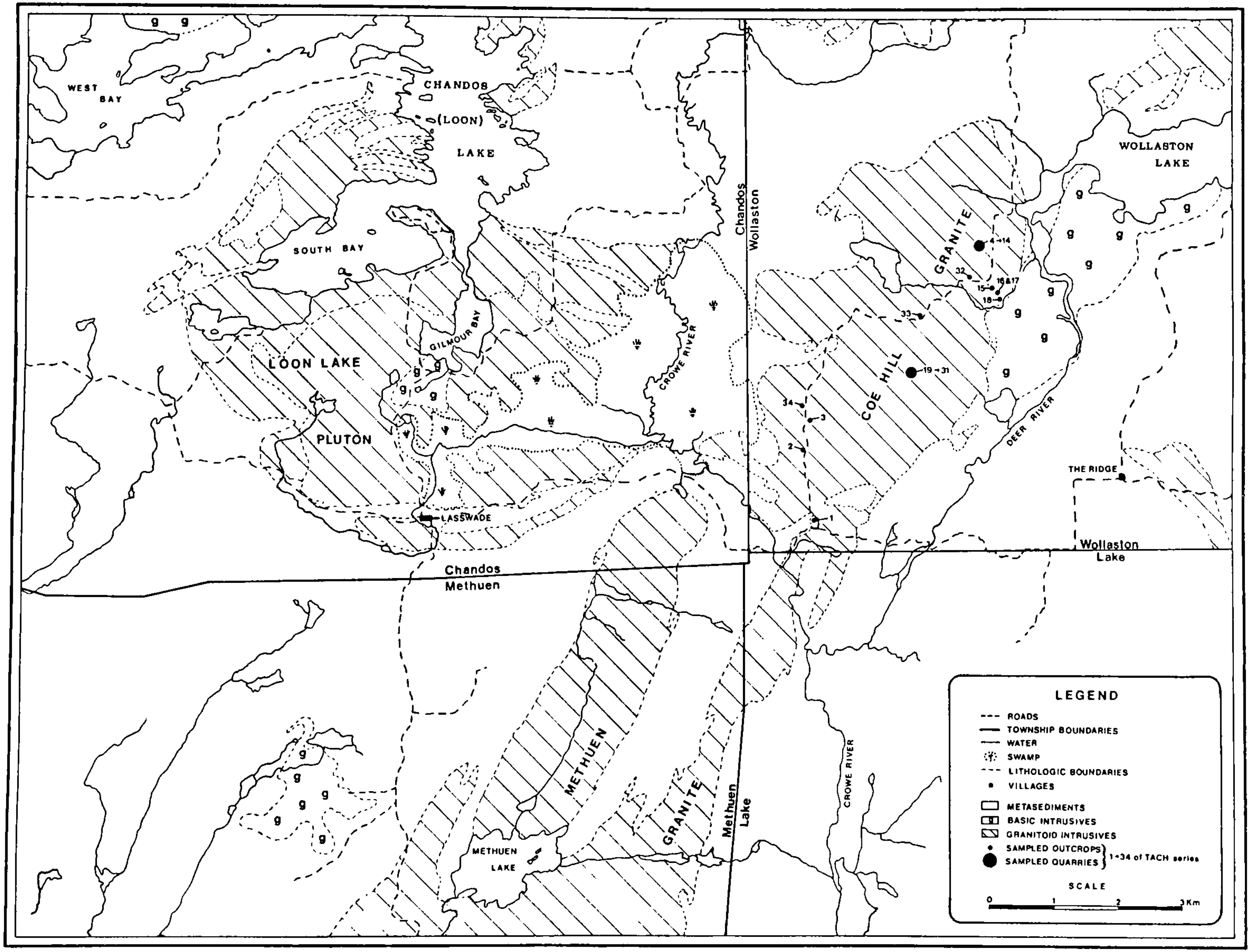
The interior of the Coe Hill granite is easily accessible via a north-south trending county road. This gravel roadway lies between the east-west trending highway no. 620, to the north of the pluton and the east-west trending Lasswade - The Ridge road to the south. Numerous outcrops

TABLE 1.1

Index of Samples From the Coe Hill Granite

Sample[1]	Location[2]
Quartz Monzonites of the Pluton Proper	
1 → 3	southern-most region of the pluton
4 → 6 and 8 → 14	northeastern quarry
19 → 31 and 33	south central quarry
Contact Zone Gneisses	
15 and 18	contact between the pluton and the Wollaston Lake gabbro
Aplite Dyke	
17	contact between the pluton and the Wollaston Lake gabbro
Mafic Xenolith	
7	northeastern quarry

[1]from the TACH series of samples
[2]refer to Fig. 1.3; map of the study area



MODIFIED AFTER HEWITT(1961,1962), LAAKSO(1968) & SHAW(1962)

FIG.1.3 Map of the Study Area

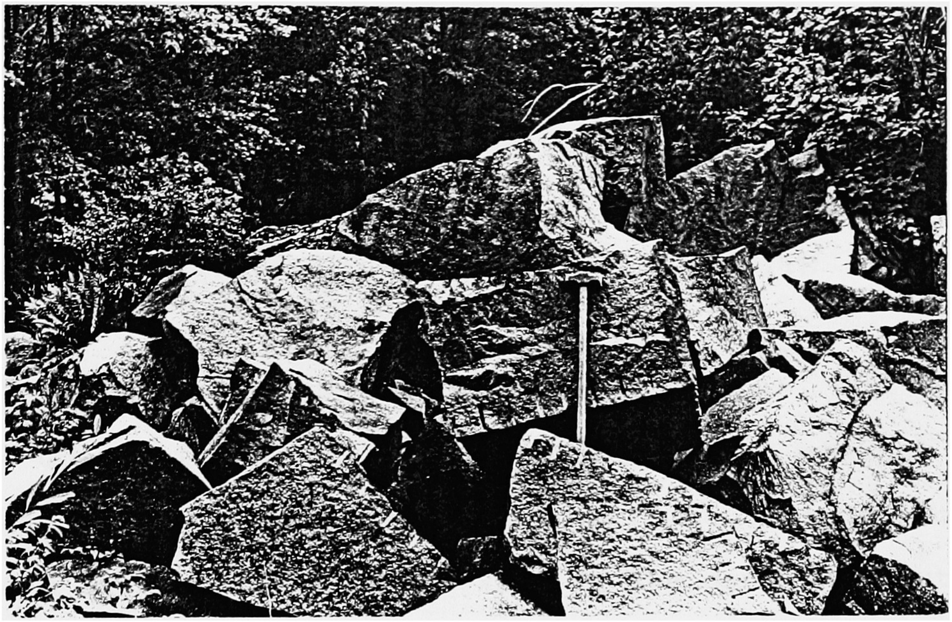
are visible along this roadway and excellent, fresh, samples may be acquired from the two abandoned granite quarries in the central and northeastern areas of the pluton (Figs. 1.3, 1.4 and 1.5). Further accessibility is provided by a number of small paths and primitive roadways that crosscut the main county road.

1.4.2 Physiography

The physiography of the study area consists of gentle undulatory hills and valleys with a minimal relief. Gillroy Lake, a small 1 km long body of water is situated in the west central area of the pluton. The northern-most quarter of the study area, west of Wollaston Lake - mouth of the Deer River, is swampy. A greater, more in depth physiographical description of Wollaston Township is provided by Hewitt (1962).

Figure 1.4 Illustration of the availability of fresh samples from the abandoned Upper Canada Granite Quarries (operational from 1940 to 1941) in the central portion of the pluton. Source of samples 19 to 31.

Figure 1.5 Photograph of abandoned Ebonridge Quarries Ltd. granite quarry (operational from 1921 to 1930) in the northeastern portion of the pluton. Source of samples 4 to 14.



CHAPTER 2

GEOLOGY AND PETROGRAPHY OF THE COE HILL GRANITE

2.1 GENERAL FEATURES OF THE PLUTON

The Coe Hill granite is an irregular shaped pluton approximately 11 sq. km. in area with a north-south length of 6.4 km. and a maximum width of 3.2 km. To the east and southeast the pluton is bounded by the Wollaston Lake gabbro and a series of thinly-bedded amphibolites, paragneisses and metavolcanics of the Mayo group. To the northeast and west the pluton is bounded by large bodies of amphibolites and paragneisses. South of the Wollaston Lake Township divide the Coe Hill granite passes into the Methuen granite (Fig. 1.3), the exact nature and position of this contact is unknown.

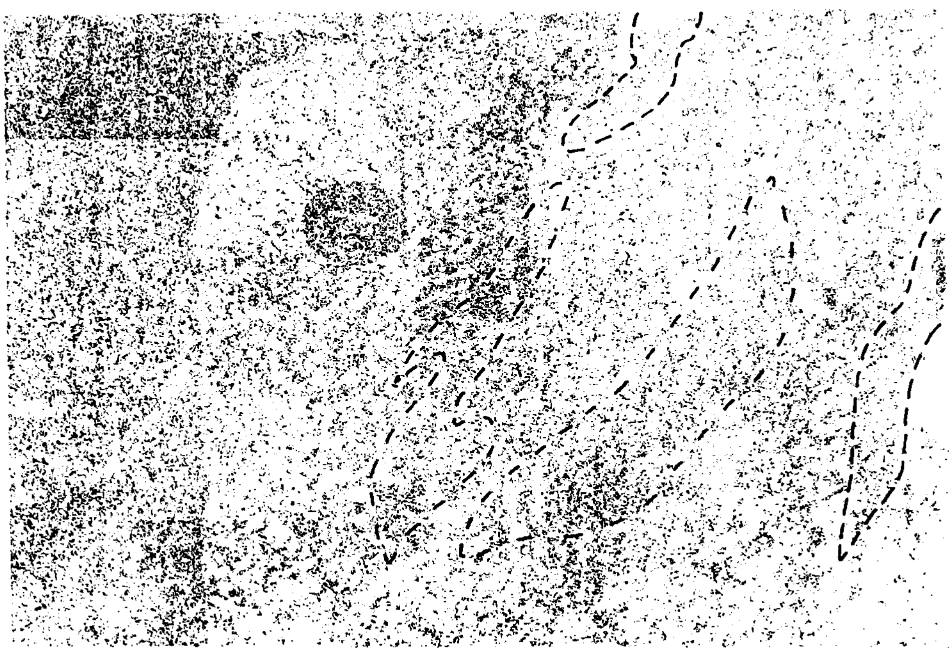
The northern contacts between the Coe Hill granite and the surrounding metasediments, observed by Hewitt (1962), are little affected by the intrusion and show no border migmatic zone nor any apparent metamorphic aureole. The other contacts lack this simplicity as they are often irregular with many tongues of the granitoid intruding into the surrounding country rocks (Fig. 2.3) and the assimilation of xenoliths of the country rock in an augen gneiss texture (Fig. 2.2). These features are especially prominent along the eastern boundary between the pluton and the Wollaston Lake gabbro where a 150 meter wide metamorphosed and brecciated zone exists. This contact zone grades into a banded quartzo-feldspathic-foliated biotite region at more distal (from 15 m to 150 m from the contact) areas from the contact.

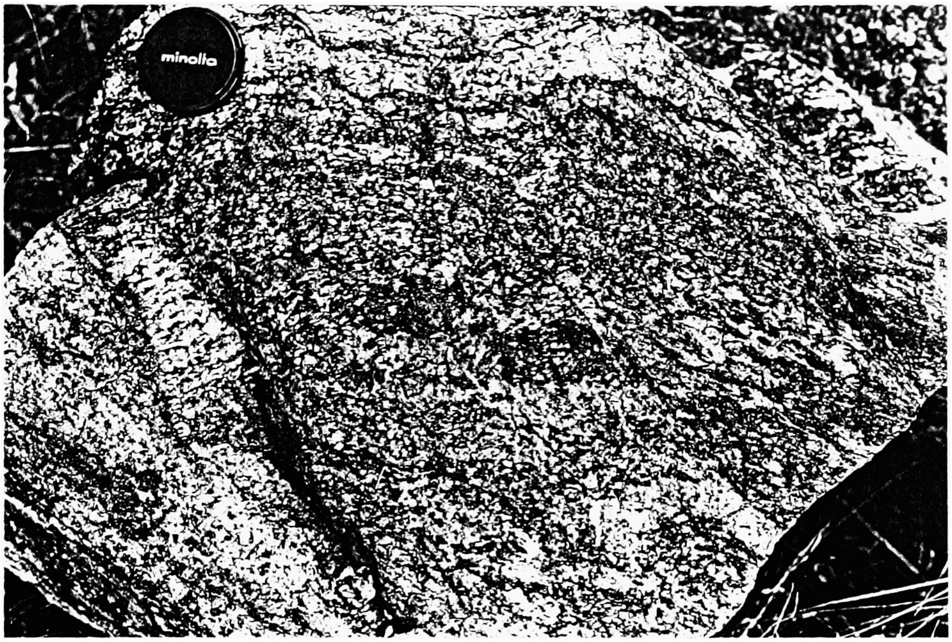
In the southern half of the pluton there exist a number of large irregular shaped gabbroic, paragneissic and amphibolite inclusions varying in size from 30 to as large as 750 m in length. Hewitt (1962) interpreted these inclusions to represent pendants of roof material in the granitoid intrusion.

As has been mentioned earlier two distinct trends of folding in this region produce synformal, anticlinal, basin and domal structures. The Coe Hill granite is generally conformable with the surrounding rocks but is structurally independent of these regional fold patterns. This feature is illustrated by the discontinuous nature of fold trends within the pluton and the difference in the dip of the foliation, within the granitoid, compared to the country rocks. From these observations it would appear that the pluton has not been affected by the main events of the Grenville metamorphism, believed in this region to have occurred 1,100 million years ago.

Figure 2.1 Banding of foliated biotite grains parallel to contact in the contact metamorphic zone.

Figure 2.2 Assimilation of lenticular elongate mafic xenolithic inclusions.




minolta

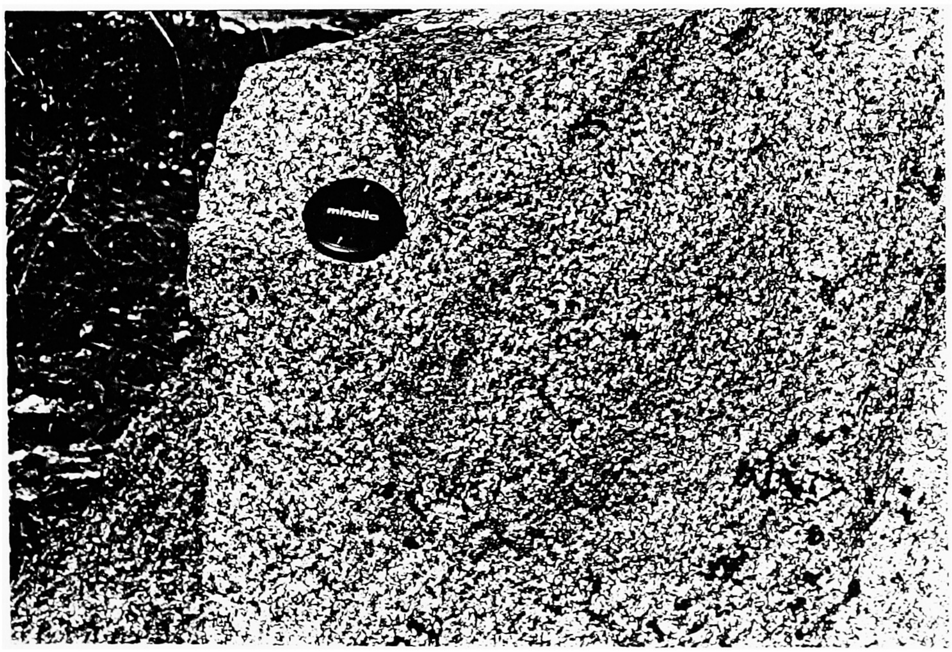
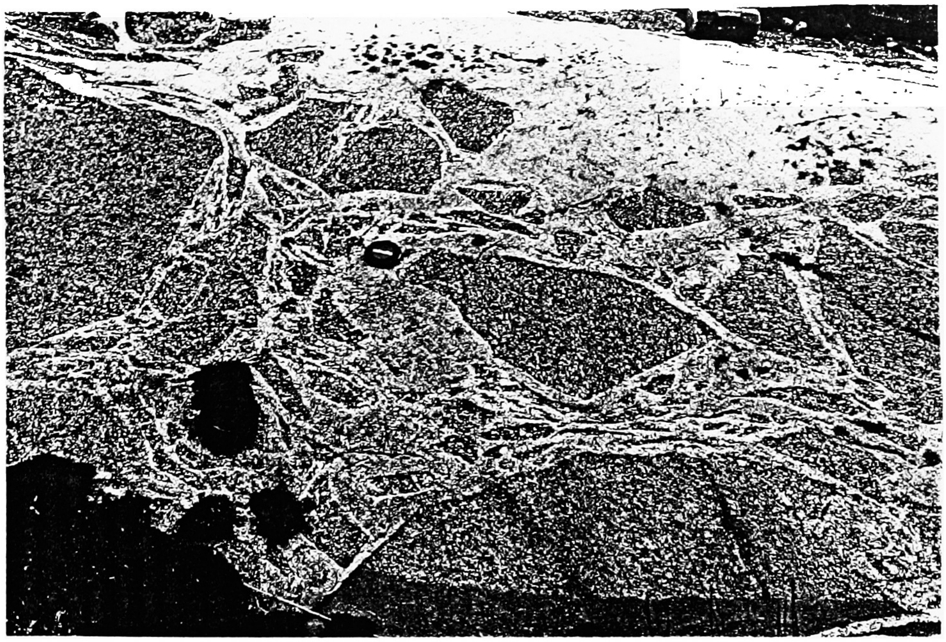
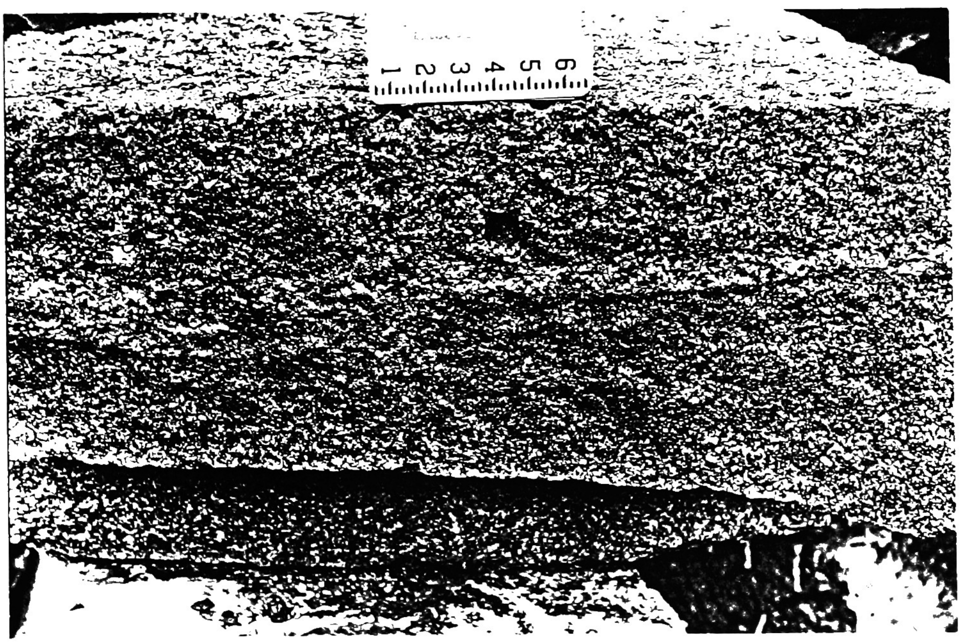

minolta

Figure 2.3 Contact breccia zone showing the rotation of included grains with the introduction of a fluid magma. Upper left hand corner shows introduction of magma into laminated amphibolite.

Figure 2.4 Discordant aplite dykes easily distinguished from quartz monzonite of pluton proper by fine grained nature and light colour.




1 2 3 4 5 6

2.2 PETROGRAPHY

2.2.1 Introduction

The Coe Hill granite proper consists of a medium to coarse grained massive quartz monzonite (Fig. 2.5) cut discordantly by 3 to 5 cm thick aplite veinlets or dykes (Fig. 2.4) and, containing in some areas, ubiquitously distributed elongate, sub-angular mafic xenoliths (Fig. 2.2). These xenoliths range in size from 1 cm by 1 cm to as large as 5 cm by 15 cm and show varying degrees of assimilation within the granitoid.

The modal composition, acquired from point counts of representative outcrop samples: 1, 2, 3, 10, 11, 27 and 31 of TACH series (Table 2.1) have been classified according to the system used by Dostal (1972, p. 88) "according to the modified Johannsens (1932) system" (Fig. 2.5). Modal compositions of the rocks shown in this diagram are given in Table 2.1. These analyses were acquired from 1,000 to 1,500 point counts per thin section, performed on ten sections. The sample locations are illustrated on the Map of the Study Area (Fig. 1.3) and sample types are listed in the accompanying Table 1.1. Most samples are of a quartz monzonite composition, but depending upon where they were sampled may show variable characteristics. Examples of thos variations may be seen in the samples acquired from the metamorphosed contact zone, xenolithic inclusions and the aplite dykes. These various

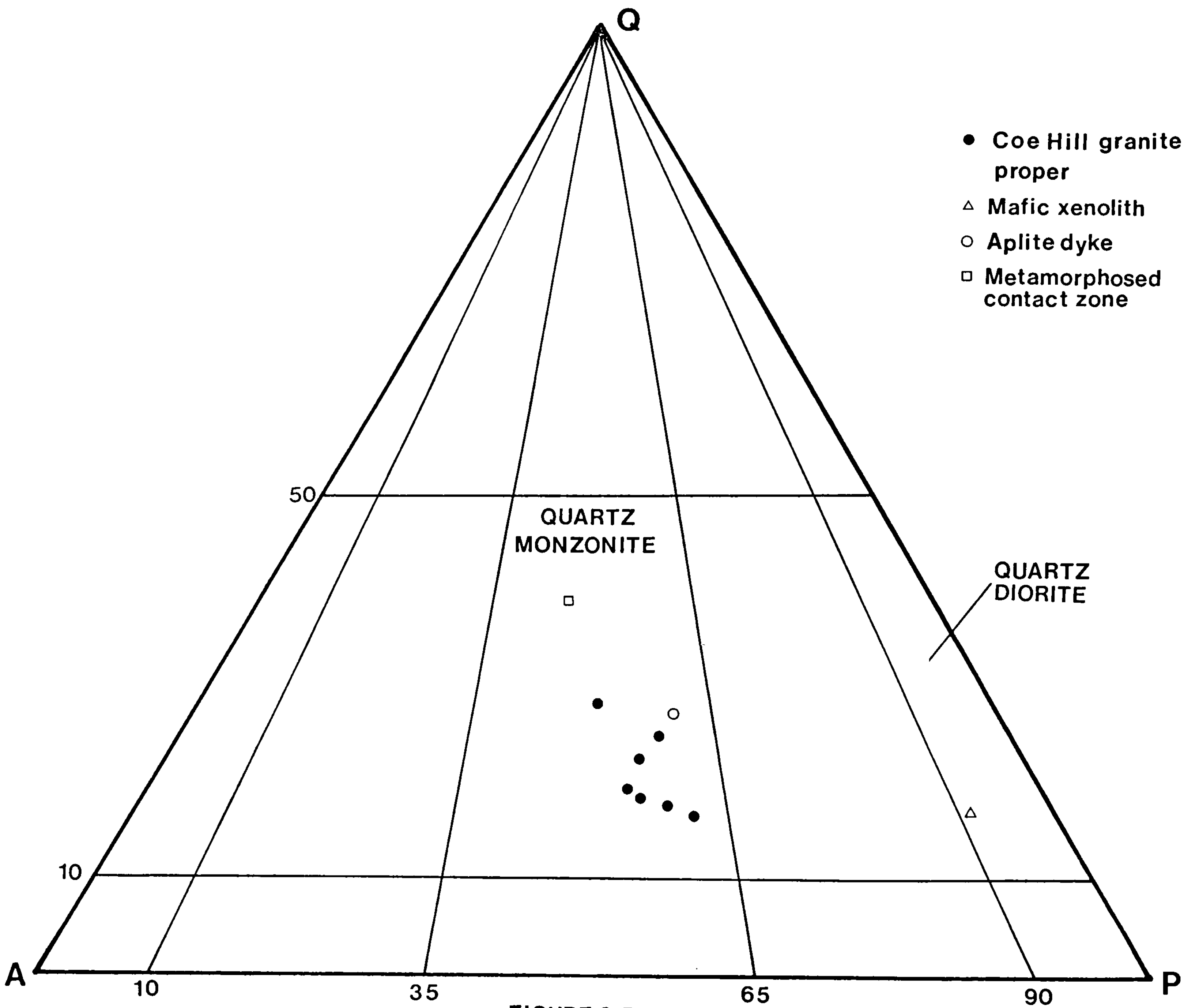

Q
A
P
50
10
10
35
65
90
QUARTZ MONZONITE
QUARTZ DIORITE
● Coe Hill granite proper
△ Mafic xenolith
○ Aplite dyke
□ Metamorphosed contact zone

FIGURE 2.5

Figure 2.5 Distribution of the modal analyses in the Quartz (Q)-Potassium feldspar(A)-Plagioclase feldspar(P) system.

TABLE 2.1

Modal Analyses of Rock Samples From the Coe Hill Granite

Sample No.	Q	Kf	Pl	Bi	Hb	Opq	Sph	Others
TACH 1	15.3	30.3	42.4	8.0	0.3	0.9	2.8	0.5(AT*Z)
TACH 2	14.2	27.8	44.1	10.4	-	1.9	1.3	0.5(AZ)
TACH 3	14.9	28.9	34.9	15.2	-	1.2	1.9	2.8(MAZ)
TACH 10	16.9	32.4	37.5	8.3	0.6	1.3	2.1	0.8(ZCT)
TACH 11	19.6	29.7	37.0	10.1	0.4	0.8	1.8	1.0(CFAZAl)
TACH 27	22.0	27.5	38.4	6.4	-	2.4	1.5	1.8(MAZ)
TACH 31	26.0	32.0	33.4	4.2	-	2.0	2.0	1.9(MCAZ)
TACH 7	10.1	4.5	42.0	22.0	13.4	1.1	5.5	1.3(CATZF)
TACH 17	30.4	27.0	22.4	17.7	-	1.2	trace	1.2(CEMA)
TACH 18	23.6	25.6	38.0	6.2	-	0.3	0.5	6.0(F†ZAAl†)

Abbreviations for Table 2.1 (Principle minerals)

Q Quartz
Kf Potassium feldspar
Pl Plagioclase
Bi Biotite
Hb Hornblende
Opq Opaque minerals
Sph Sphene

Abbreviations for Table 2.1 (Others)

A Apatite
Al Allanite
C Carbonate
E Epidote
F Fluorite
M Muscovite
T Tourmaline
Z Zircon

*indicates trace amount of "other" composition
†indicates that this is the larger proportion of the "other" composition

samples will be discussed separately from the quartz monzonites of the pluton proper (although in some instances they have a quartz monzonite composition) in order to emphasize their differences.

2.2.2 Quartz Monzonite

As was previously mentioned, the composition of most thin section samples is that of a quartz monzonite (Fig. 2.5, Table 2.1). These samples were acquired throughout the pluton and represent all the variations observed in the pluton (Fig. 1.3, Table 1.1). Generally they consist of medium to coarse grained 1 mm to 5 mm grains with a mean size of 2.0 mm, in the northern half of the pluton, while the southern half shows a slightly coarser fabric with mean grain sizes of approximately 3.5 mm. Colour is from light grey to light pink, a reflection of the abundance of white or pink feldspars along with grey quartz. Colour index ranges from approximately 7 - 20 and the rocks would be classified as leucocratic. Mafic minerals are predominantly biotite and opaques while the rest of the quartz monzonite contains amounts of plagioclase and potassium feldspars, quartz, sphene and minor to trace amounts of fluorite, apatite, allanite, epidote, secondary muscovite, tourmaline and carbonates.

Plagioclase feldspar exists as anhedral grains from 0.1 to as large as 5.0 mm in size. Compositions vary from

An_{10} to An_{14}. Plagioclase commonly occurs with albite twins and less commonly with pericline and combined carlsbad-albite twinning. Sericitic alteration of the plagioclase ranges in extent from minor to extreme with as much as 35 percent of the grain altered to secondary sericite (Fig. 2.6).

Potassium feldspar occurs as anhedral grains from 0.1 mm to 5 mm in size. Most of the larger grains show a micro-perthitic texture with amounts of plagioclase, in string, band or patch inclusions (Fig. 2.7), varying from 5 to 20 percent of the grain. Perthitic texture occurs with microcline cross-hatched twinning (Fig. 2.7). Smaller grains are most often free of the perthitic intergrowths of plagioclase and show excellent, well-developed microcline twinning.

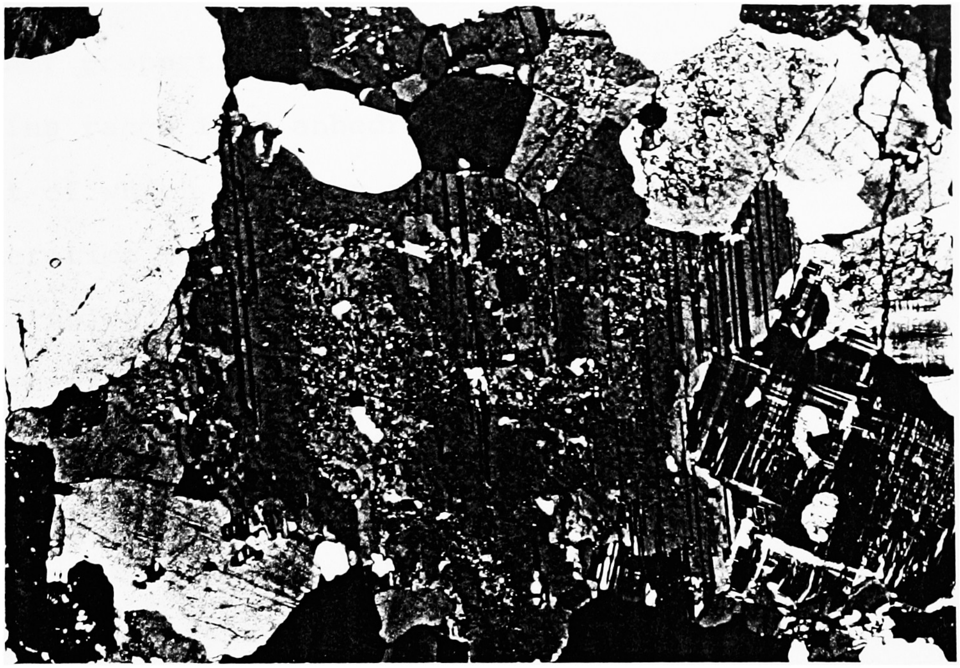
Quartz occurs as irregular interstitial 0.1 mm to 2.0 mm grains with undulose extinction and is often present as minute inclusions in feldspars.

Biotite exists as ubiquitously distributed irregular flakes or as elongate tabular grains up to 3 mm in length (Figs. 2.8 and 2.9). Pleochroism may be either: X- pale, straw yellow, Y-Z-deep brown (occurring most often); or as X-pale yellow, Y-Z-grayish green. Biotite is often altered to sphene as may be seen by the presence of irregular biotite grains surrounded by generally anhedral to subhedral grains of sphene (Figs. 2.8 and 2.10). Biotite regularly occurs with zircon inclusions showing strong radioactive halos (Fig. 2.10).

Opaque minerals, ranging in size from 0.1 mm to 0.8 mm,

Figure 2.6 Photograph illustrating sericitization of medium grained (3 mm) plagioclase feldspar.

Figure 2.7 Microcline cross hatched medium grained (3.5 mm) potassium feldspar showing string inclusions of plagioclase in a micro-perthitic texture.



form a minor proportion of the mineral content of all samples. These grains range from anhedral to euhedral in crystal shape, the extent of which is often a function of the severity of their alteration to sphene (Fig. 2.8).

Hornblende is found as minor to trace amounts in a few samples except the mafic xenolith where it is a common abundant mineral. In the quartz monzonites it occurs as 0.1 to 0.25 mm anhedral to subhedral ubiquitously distributed grains with pleochroism X-light yellow green; Y-olive green; Z-dark green and extinction angles ranging from 18 to 28 degrees.

As mentioned previously sphene is quite common as a late stage deuteric mineral occurring as an alteration corona associated with biotite and opaque minerals (Fig. 2.8). It may also be present as individual euhedral grains as large as 1.0 mm by 1.5 mm (Fig. 2.10).

Besides these minerals the quartz monzonite of the Coe Hill granite has minor amounts of allanite, usually occurring as irregular altered grains ubiquitously distributed throughout the occasional sample. The altered or amorphous form is commonly due to the breakdown of the space lattice of the mineral due to radioactive emanations (Kerr, 1977). Apatite is also common in minor to trace amounts as small subhedral to euhedral six-sided prismatic grains ubiquitous throughout the samples. Secondary muscovite in the form of sericite alteration may represent up to 4 percent of the mineral composition in some samples. Epidote, tourmaline, fluo-

Figure 2.8 Irregular flakes of biotite and opaque grains altering to anhedral, irregular (0.5 mm) grains of sphene.

Figure 2.9 Elongate, foliated tabular (2 mm) grains of biotite. Note the ubiquitous zircon inclusions, identified by the radioactive halos.

rite and carbonates infrequently form trace amounts of the mineral composition of samples.

2.2.3 Aplite Dykes

Discordant aplite veins (sample TACH-7) from 3 cm to 5 cm thick are visible throughout the pluton (Fig. 1.3, Table 1.1). They are generally very fine to fine grained, massive allotriomorphic granular with mineral compositions and textures similar to the Coe Hill quartz monzonites (Fig. 2.5). Features that distinguish these aplite dykes from the quartz monzonites of the pluton proper are their overall fine grained nature, with most minerals approximately 0.5 mm in size (potassium feldspar exists with anomalous grains as large as 2.0 mm), the lighter pink to white colour, and in thin section, the overall allotriomorphic texture.

2.2.4 Mafic Inclusions

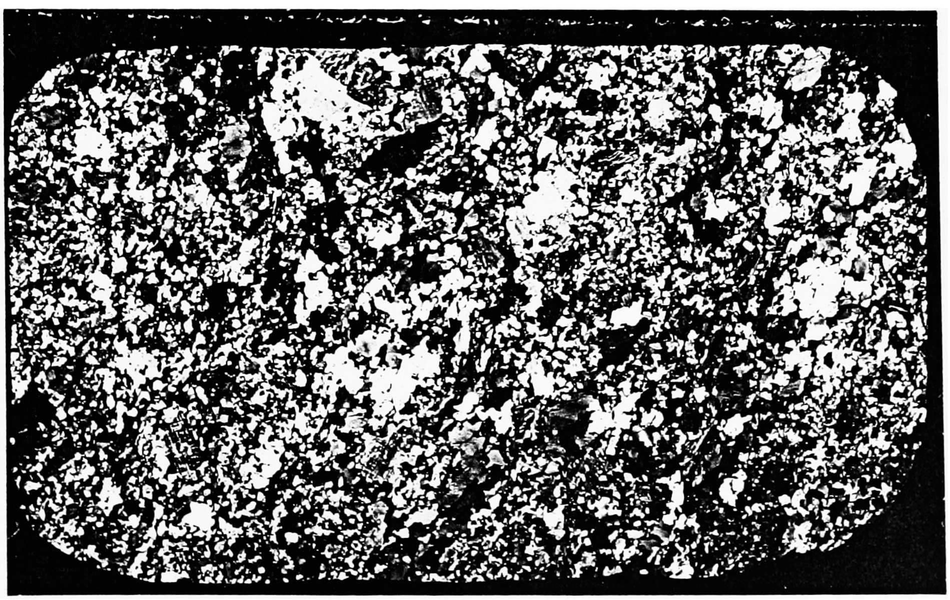
Near the contact zones, and in the southern half of the pluton (near the large inclusions of country rock), xenoliths of the country rocks surrounding the pluton are especially prominent (Fig. 1.3, Table 1.1). Sample TACH-7 is an example of one such xenolith. This sample shows a number of features that differ from the quartz monzonite of the pluton proper. These features include a generally finer grained allotriomorphic to hypidiomorphic texture with grains ranging from 0.1 to 3.0 mm and a mean grain size of 1.0 mm. These rocks have an overall quartz granodiorite composition (Fig. 2.5) and the abundance of mafics are easily discernible from the rocks of the pluton proper. These mafics include 0.1 mm to 1.0 mm anhedral to subhedral hornblende, fine grained ubiquitous, anhedral opaque minerals, 0.5 mm to 3.0 mm elongate anhedral to subhedral flakes of biotite and extensive alteration of all these mafics to yield 0.1 mm to 0.8 mm anhedral to euhedral, rhombic grains of sphene (Figs. 2.8 and 2.10). All the other major minerals present in the Coe Hill granite quartz monzonite are also present. These minerals show similar sericitic alteration of plagioclase feldspars, perthitic textures of potassium feldspars and undulose extinction of quartz.

2.2.5 Contact Zone Gneiss

The thin section, cut from the rocks sampled from the contact zone between the Coe Hill granite and the Wollaston Lake gabbro (Fig. 1.3, Table 1.1), is a banded, foliated, biotite-quartz monzonite. The bands of foliated, elongate biotite (Fig. 2.1), the rotation of inclusions by invading magma, observed at the contact breccia zone, along with the presence of magma invading the country rocks (Fig. 2.3) are most likely due to the deformation resulting from the movement of magma during the emplacement of the pluton. Saha

Figure 2.10 Photograph of 1.0 mm euhedral grain of sphene in association with biotite. Biotite occurs with up to 0.1 mm inclusions of zircon.

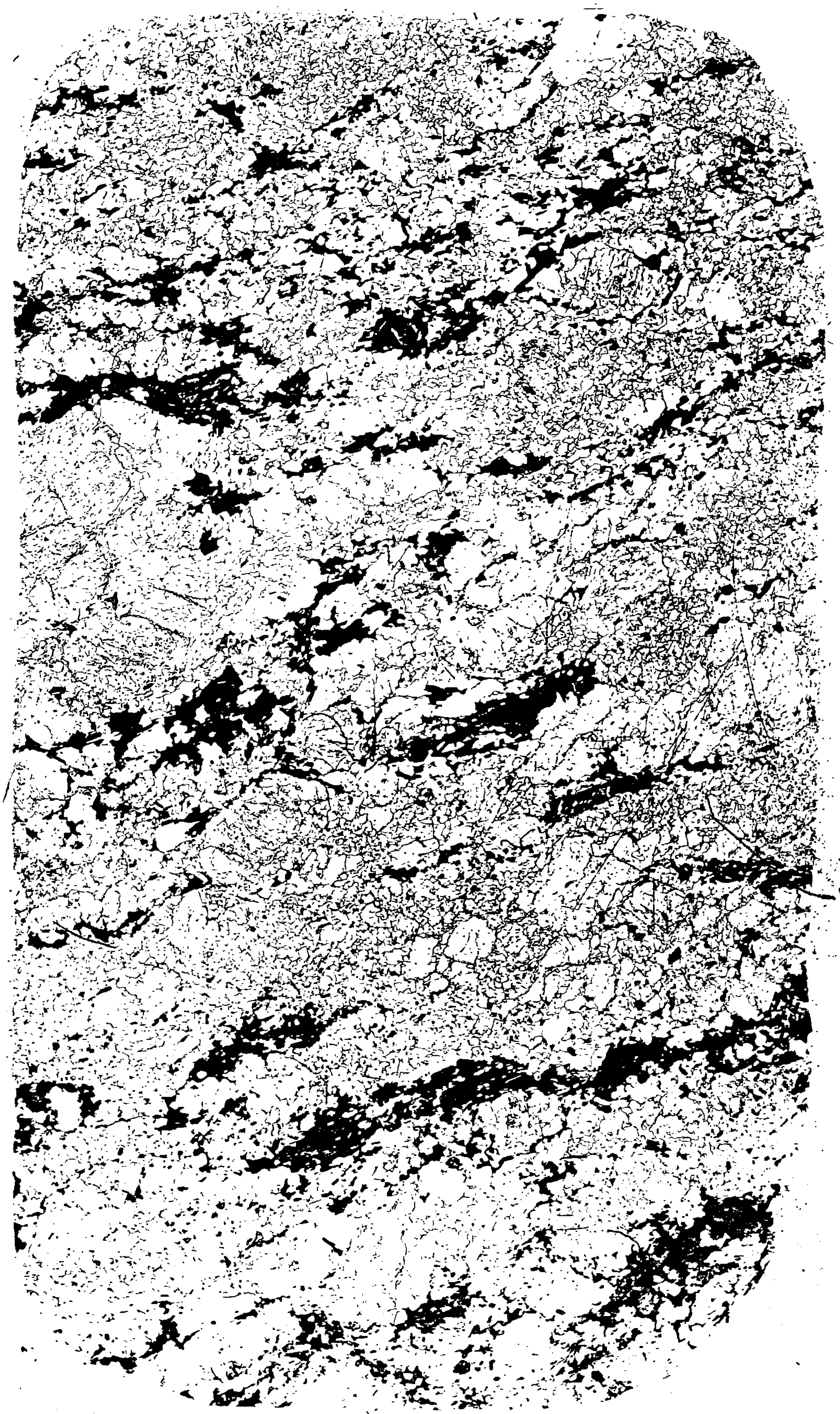
Figure 2.11 Bimodal granularity evident in sample from the contact gneissic zone. Note extreme bimodal character of micro-perithitic potassium feldspars.



(1959) observed similar features at the contact between the country rocks that surround the Loon Lake pluton.

On a microscope scale these rocks exhibit several properties which are conspicuously different from those observed in the pluton proper. They are generally fine grained to medium grained hypidiomorphic with an overall quartz monzonite composition (Fig. 2.5), extreme foliation of elongate biotite grains, minor elongation of other minerals and a bimodal grain distribution (Figs. 2.11 and 2.12). Bimodal granularity is especially prominent in potassium feldspars which may occur as 0.1 mm to 4.0 mm anhedral grains, at distal regions from the foliated bands, to 0.1 mm to 0.25 mm grains at proximal distances (Fig. 2.11). Within these bands biotite occurs in a lepidoblastic texture of subhedral to euhedral elongate blades up to 2 mm long with grain widths no greater than 0.2 mm. Grain shapes of feldspars and quartz are also related to their proximity to those foliated bands with slightly elongate grains occurring proximal to the banding. Differences in the mineralogy between the pluton proper and the sample from this area are evident in the presence of subhedral to euhedral 0.1 mm to 0.25 mm, ubiquitously distributed fluorite, the presence of as much as three percent allanite and minor amounts of slightly elongate, ubiquitously distributed tourmaline. Besides these examples all other minerals and their textures are similar to those observed in the quartz monzonites of the Coe Hill granite proper.

Figure 2.12 Enlarged photograph of thin section from contact zone (Fig. 2.11), under plain light. Bimodal granularity remains evident while the foliation of elongate, tabular grains of biotite are illustrated.



CHAPTER 3

GEOCHRONOLOGY

3.1 RESULTS OF Rb-Sr ISOTOPE ANALYSES

The results of the Rb-Sr whole rock analyses, performed on homogeneous looking samples acquired throughout the Coe Hill granite, are illustrated in Fig. 3.1. The isochron of Fig. 3.1 defines an event that occurred 1063 ± 21 M.a. with an initial ratio of 0.7040 ± .0005. Structural, petrographic and geochemical observations of the pluton suggest that this date represents the age of emplacement, (refer to Discussion, Chapter 5).

Due to the heterogeneous character of the samples acquired from the contact zone (samples TACH-15, CH 1, 2, 3 and 4), and their anomalously high $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ values (relative to the samples acquired from the pluton proper), a separate diagram illustrating their positions with respect to the 1063 M.a. isochron was constructed (Fig. 3.2). This diagram serves to illustrate the large deviation in these points with respect to the 1063 M.a. isochron and further goes to illustrate the unreliable nature of these samples for geochronology. The fallible nature of these points to a geochronology study is easily illustrated by combining the 1019 ± 18 M.a. isochron (with initial ratio of 0.7276 ± .0018), produced by these heterogeneous points, with that of the 1063

M.a. isochron of the pluton proper (Fig. 3.2). This combined data yields an age of 1248 ± 15 M.a. with an initial ratio of 0.6900 ± .0005. The use of samples with anomalous isotope values, acquired from heterogeneous areas such as contact metamorphic zones, heterogeneous dykes and assimilating xenoliths, yield what Brook et al. (1972, p. 557) called an "errorchron" for:

> "... any set of data in which an investigator identifies geological error, he must assume the burden of proof that any confidence intervals (i.e., errorchron errors) that he may state are in fact real ... This can only be accomplished by extra knowledge concerning these data ..."

Thus by utilizing these additional heterogeneous points in the calculation of an isochron diagram a meaningless "errorchron" is derived and the possibility of establishing the true age represented by the homogeneous rocks of the pluton proper becomes obscured. In order to decipher the true age of the pluton physically, and if possible, geochemically and petrographically homogeneous samples must be utilized. If a heterogeneous point is present in the analyses it is up to the investigator to determine its cause before constructing an isochron.

Figure 3.1 Rb-Sr isochron diagram constructed from TACH series of whole rock samples representative of the Coe Hill granite proper.

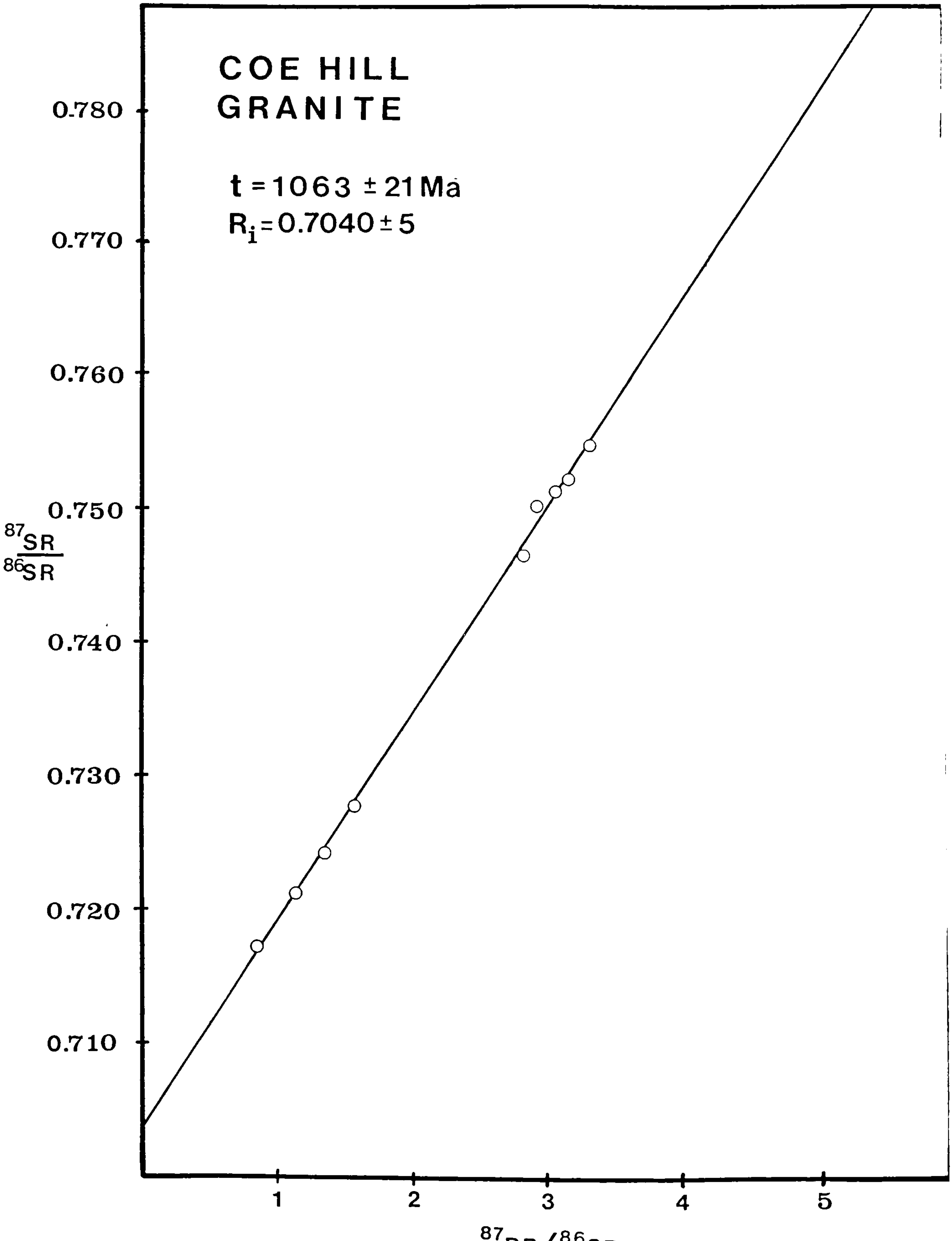
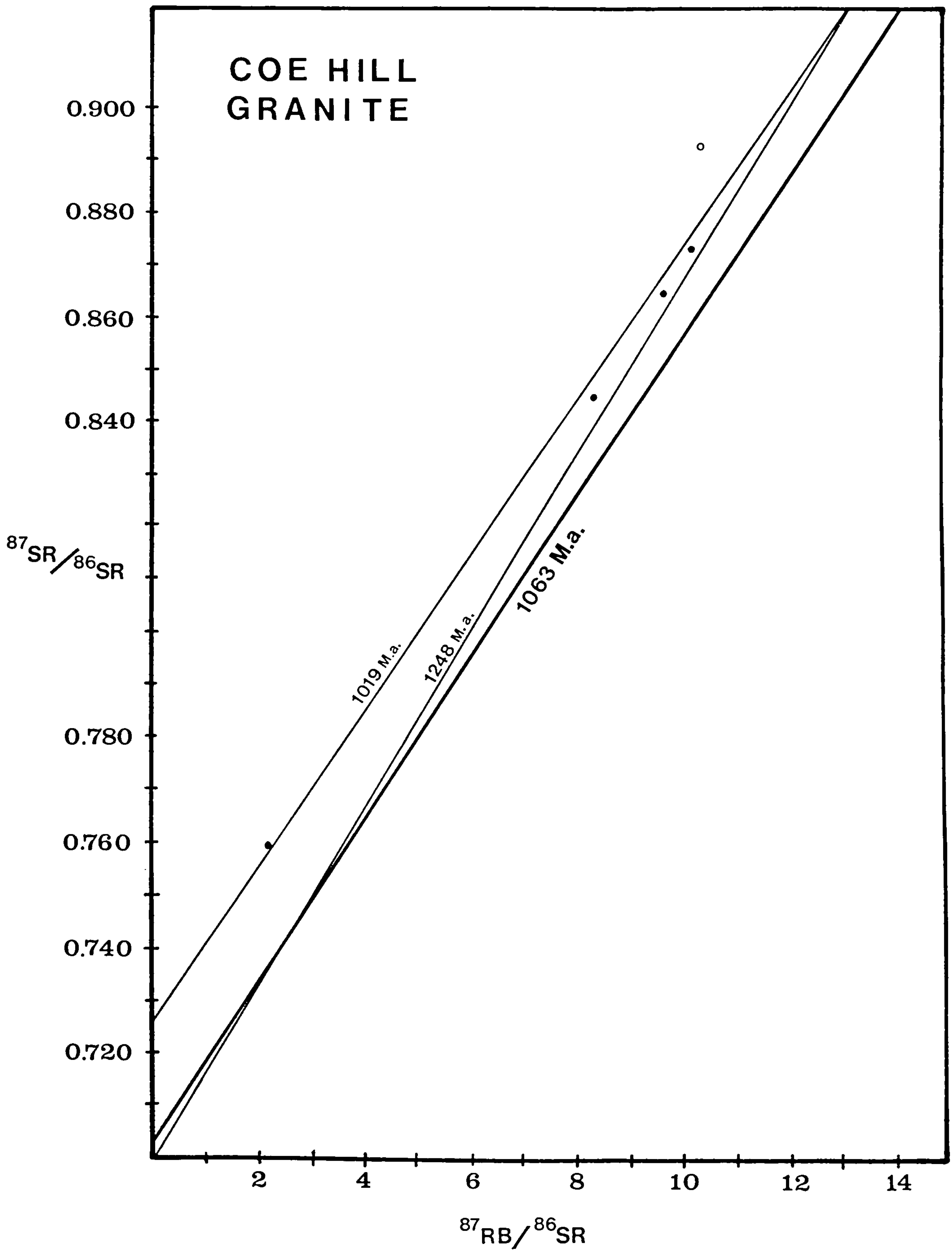

COE HILL
GRANITE
t = 1063 ± 21 Ma
R_i = 0.7040 ± 5
0.780
0.770
0.760
0.750
0.740
0.730
0.720
0.710
87SR/86SR
1
2
3
4
5
87RB/86SR

Figure 3.2 Rb-Sr isochron illustrating variations between 1063 M.a. isochron of the pluton proper and the "errorchrons" constructed from heterogeneous samples.

● CH series of samples (Heaman, unpublished data)
○ TACH series of samples


COE HILL
GRANITE
0.900
0.880
0.860
0.840
0.780
0.760
0.740
0.720
87SR/86SR
1019 M.a.
1248 M.a.
1063 M.a.
2
4
6
8
10
12
14
87RB/86SR

CHAPTER 4

GEOCHEMISTRY OF THE COE HILL GRANITE

4.1 INTRODUCTION

The results of the major element geochemical analysis and C.I.P.W. normative values, derived from this data (method of C.I.P.W. calculations from Shaw, 1968) are given in Table A.1 while Rb and Sr results are given in Table A.2.

4.2 MAJOR ELEMENT GEOCHEMISTRY

Table 4.1 compares the average values for the 10 samples of the Coe Hill granite against those of Nockold (1954), for what he has called an adamellite (potassium feldspar from 40 to 60 percent of total feldspar, with greater than 10% quartz), and the Loon Lake pluton (Dostal, 1973). A comparison of these illustrates that the Coe Hill quartz monzonite generally shows similar values for most of the major element oxides, the exception being MgO and FeO + Fe_2O_3, both of which are high in comparison to Nockold's data and the Loon Lake quartz monzonite. These high values are a reflection of the increased abundance of mafics (especially biotite), averaging approximately 8.6 percent of the mineralogy, as seen in thin sections.

The contents of the Coe Hill granite major elements have been plotted on the variation diagrams Figs. 4.1 to 4.8. These diagrams show major element variations with respect to Thornton and Tuttle's (1960) differentiation index (D.I.) "a natural quantity to use for variation diagrams of rock series since it is based on experimental data corroborated by chemical studies of igneous rocks and is a measure of the basicity of a rock" (p. 679-680). The samples from the Coe Hill granite fall suitably into the granite to alkali granite range (D.I. equals 80 to 93 percent).

Summarizing the basic trends of these diagrams, one can see that Fig. 4.1 shows most of the rocks of the Coe Hill granite to lie in a zone that is over-saturated with respect to SiO_2. Anomalously rich SiO_2 samples (SiO_2 greater than 70 percent) are those taken from the contact zone. Fig. 4.2, Al_2O_3 - D.I., shows a minor trend towards slightly increased values of Al_2O_3 with increasing basicity (lower D.I. values). K_2O - D.I. of Fig. 4.3 shows no apparent trend but instead clusters about 5 weight percent of K_2O. This assemblage of points is most likely due to the regular content of potassium feldspar amongst the various samples due to a homogeneous crystallization of these feldspars within the pluton. This trend is contrary to what is normally observed as K_2O usually shows a steady increase in content with increasing D.I. values as it is commonly held in the liquid until alkali feldspar

TABLE 4.1

Average Quartz Monzonite Compositions

	Nockolds (1954)	Loon Lake pluton	Coe Hill granite
SiO_2	69.15	70.98	68.06
TiO_2	0.56	0.36	0.69
Al_2O_3	14.63	14.74	14.03
$FeO+Fe_2O_3$	3.49	2.50	4.69
MnO	0.06	0.03	0.07
MgO	0.99	0.43	1.53
CaO	2.45	1.15	1.76
Na_2O	3.35	3.79	3.99
K_2O	4.58	5.43	4.97
P_2O_5	0.20	0.08	0.30
No. of analyses	121	12	10

crystallizes (Thornton and Tuttle, 1960). Na_2O in Fig. 4.4 has a range from 3 to 6 weight percent and is also free of any fractionating trend with variations in D.I. CaO in Fig. 4.5 shows an increase of CaO with increasing basicity. This elongate trend should be expected as Ca is a common constituent in more basic minerals such as hornblende, sphene and allanite. Similarily MgO and FeO, of Figs. 4.6 and 4.8 respectively, should show analogous trends but, although FeO does, MgO does not. This discrepancy is likely a result of a more Fe rich biotite. Weight percent of TiO_2 in Fig. 4.7 presents two clusters of points most likely in accordance with the relative abundances of sphene present in these samples. The lower crescent shaped cluster represents samples acquired from the east-central and contact zone regions while the tight circular cluster represents samples gathered throughout the pluton.

The presence or absence of trends amongst the major element oxides appears to be a reflection of the abundance of various minerals present in these samples. The trends towards increasing CaO and FeO are most illustrative of this feature as these trends are reflected in the increase in biotite along with increases in less abundant sphene, opaques, allanite and hornblende observed in thin sections (Table 2.1). Similarily the constant values of potassium feldspar and plagioclase feldspar are reflected in the major element values for K_2O, Na_2O and SiO_2.

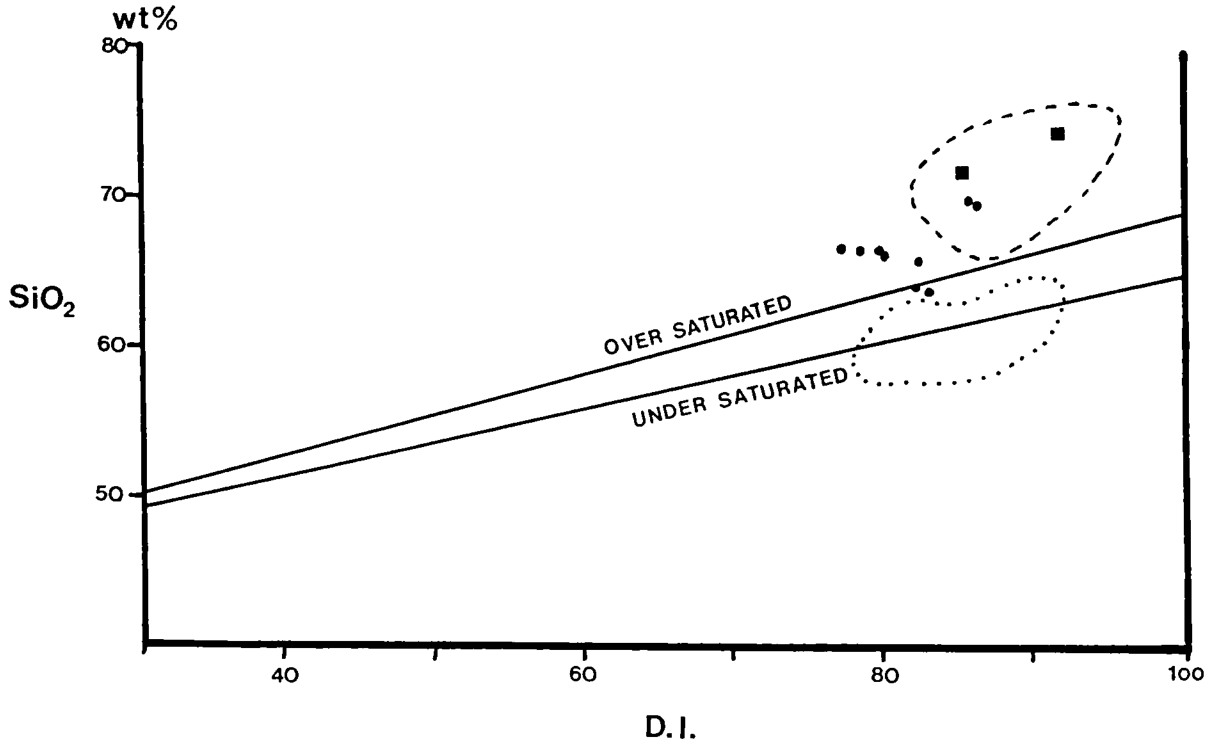

wt%
80
70
60
50
SiO_2
OVER SATURATED
UNDER SATURATED
40
60
80
100
D.I.

FIG.4.1

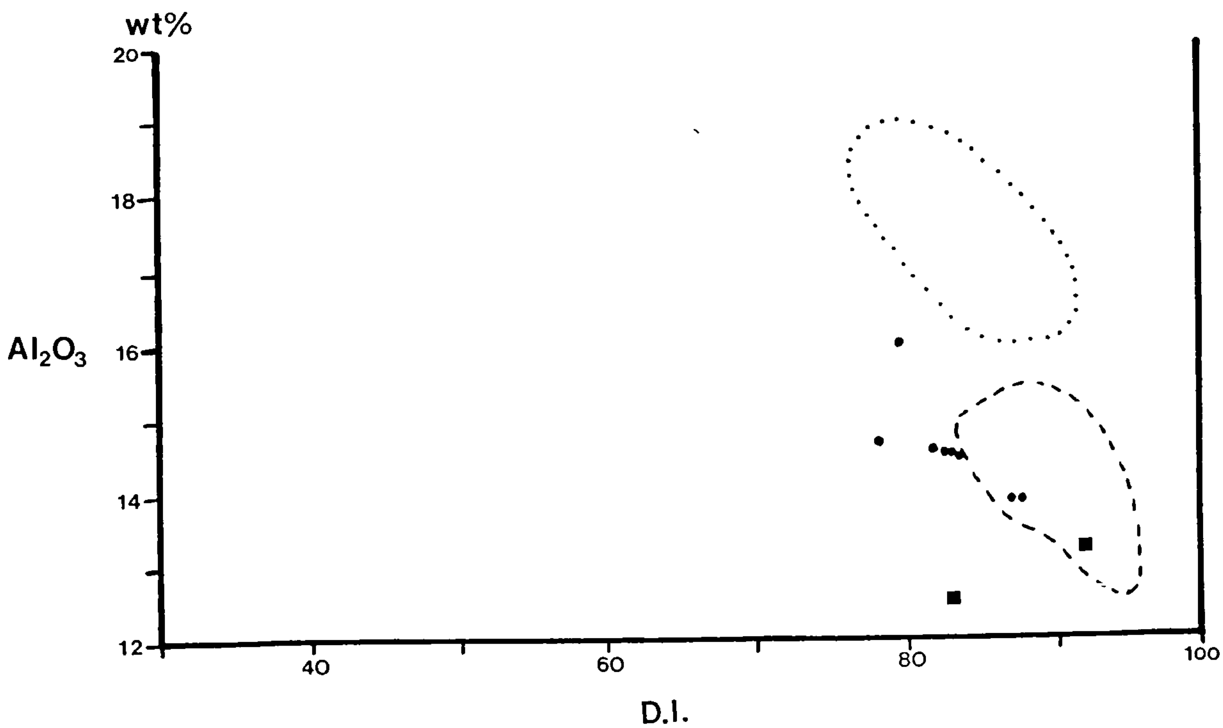

wt%
20
18
16
14
12
Al_2O_3
40
60
80
100
D.I.

FIG.4.2

Figures 4.1 to 4.8

Variations in major element oxides as a function of the differentiation index (D.I.). Broken lines outline the positions of Loon Lake pluton data.

■ Samples from the Coe Hill granite contact zone
● Quartz monzonites of the Coe Hill granite proper
....Zone of Loon Lake monzonite samples
----Zone of Loon Lake quartz monzonite samples

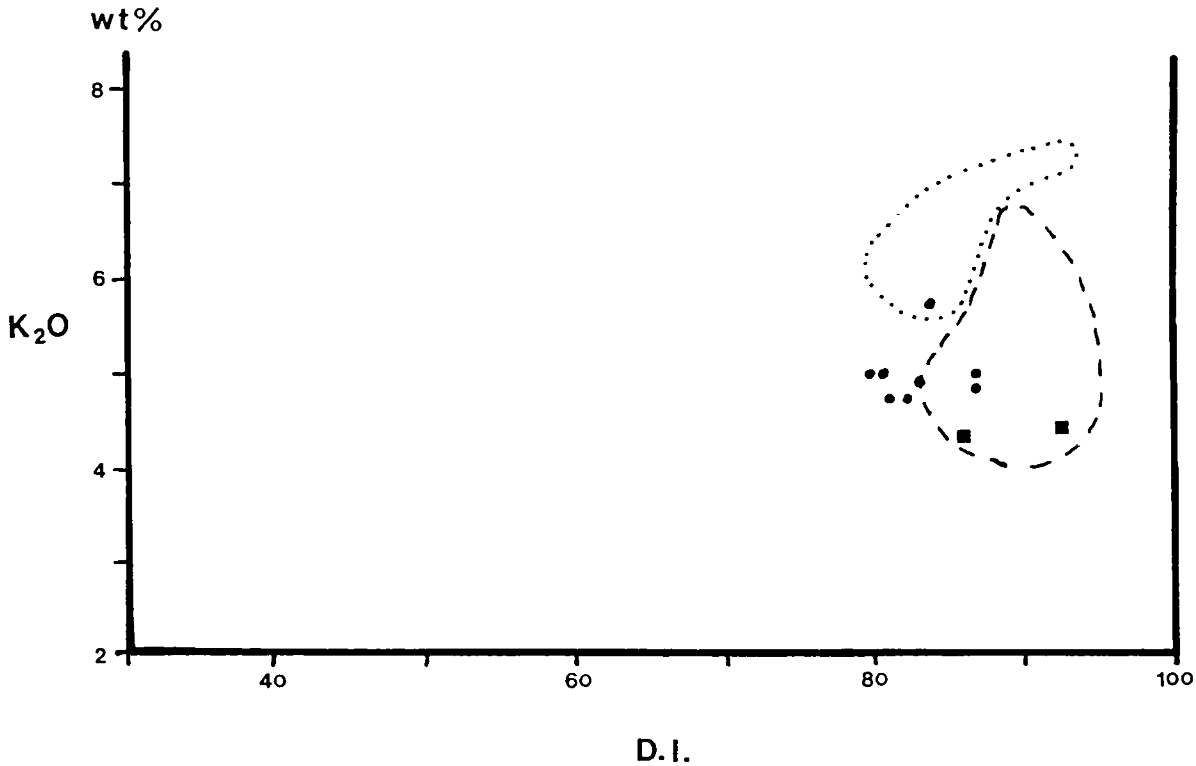


FIG. 4.3

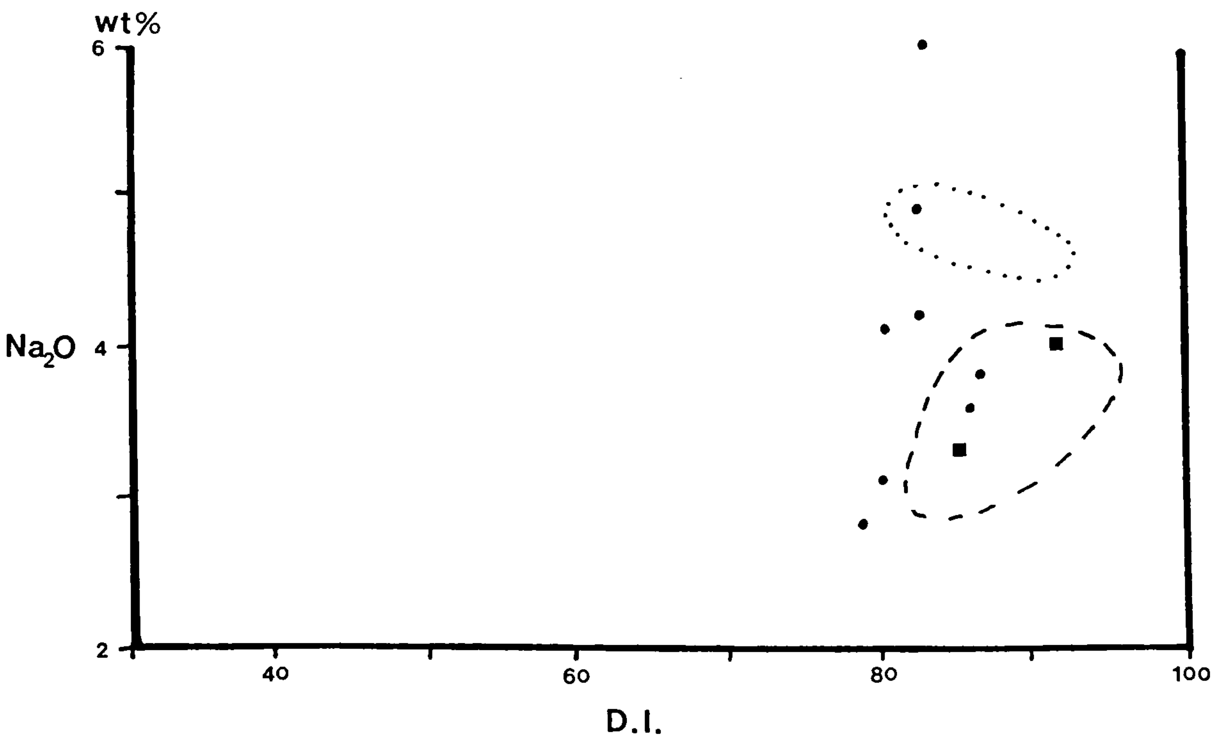


FIG.4.4

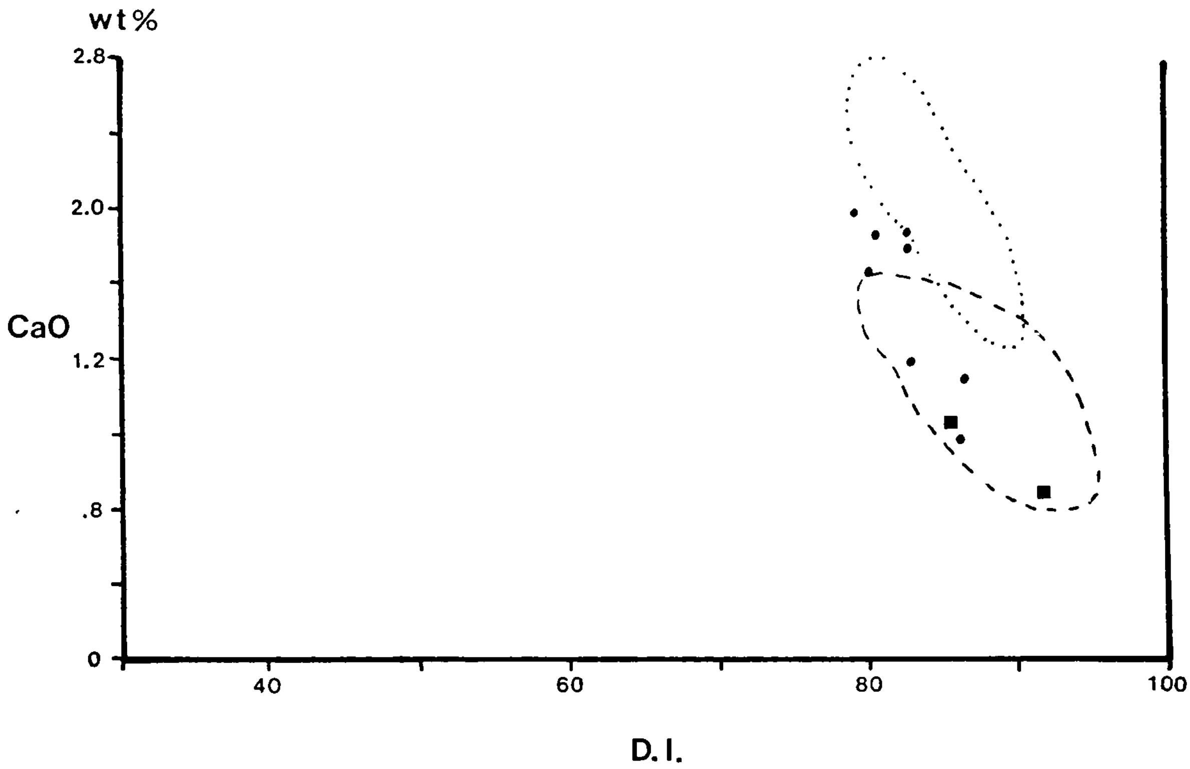


FIG. 4.5

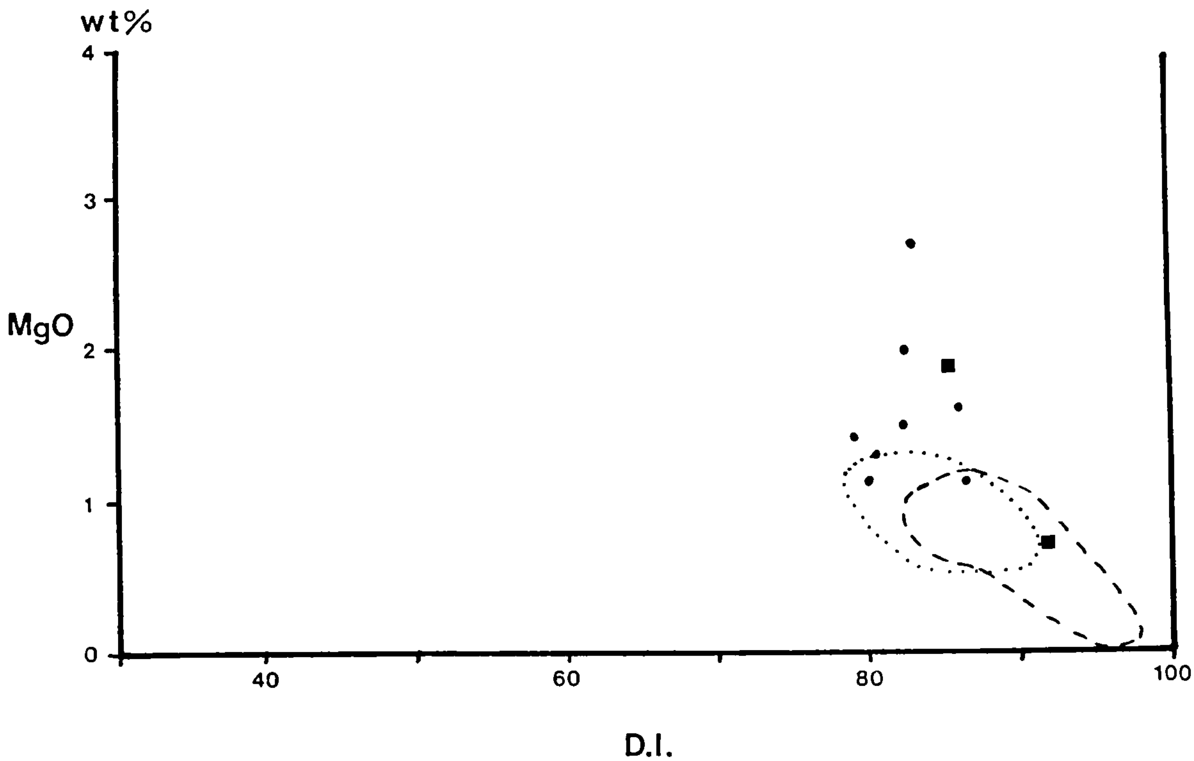


FIG. 4.6

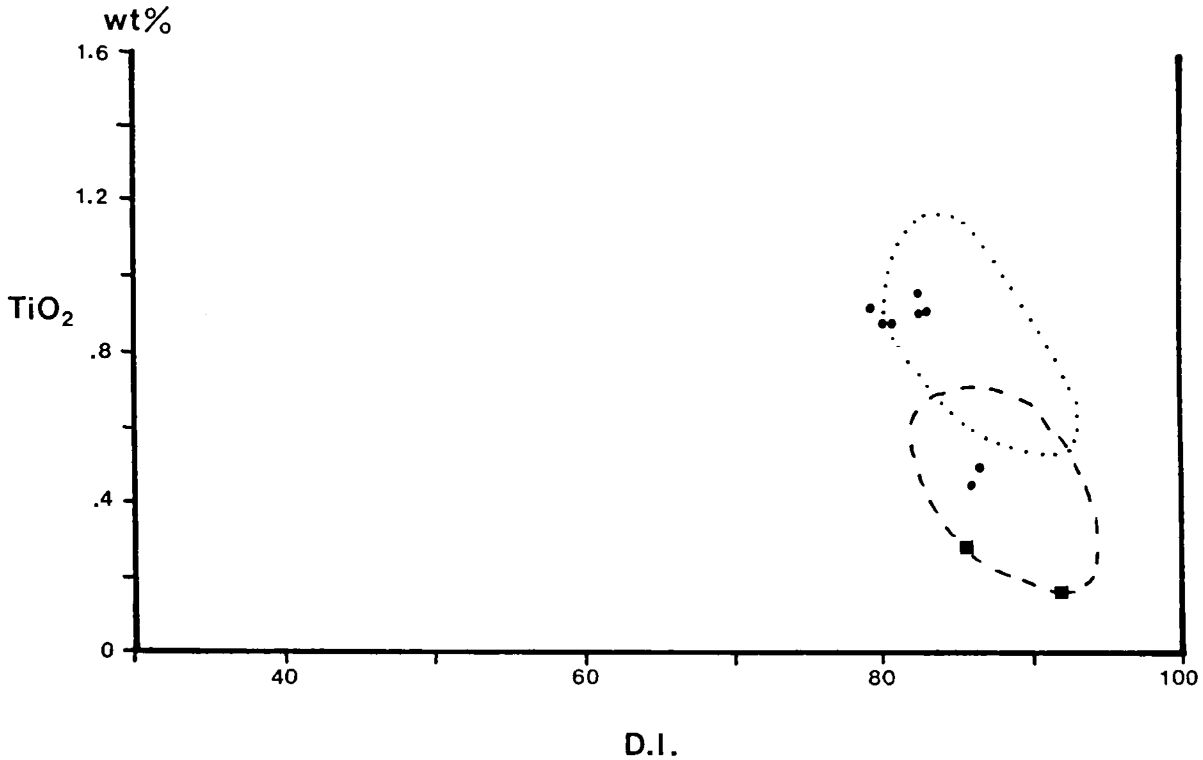

wt%
1.6
1.2
TiO2
.8
.4
0
40
60
80
100
D.I.

FIG. 4

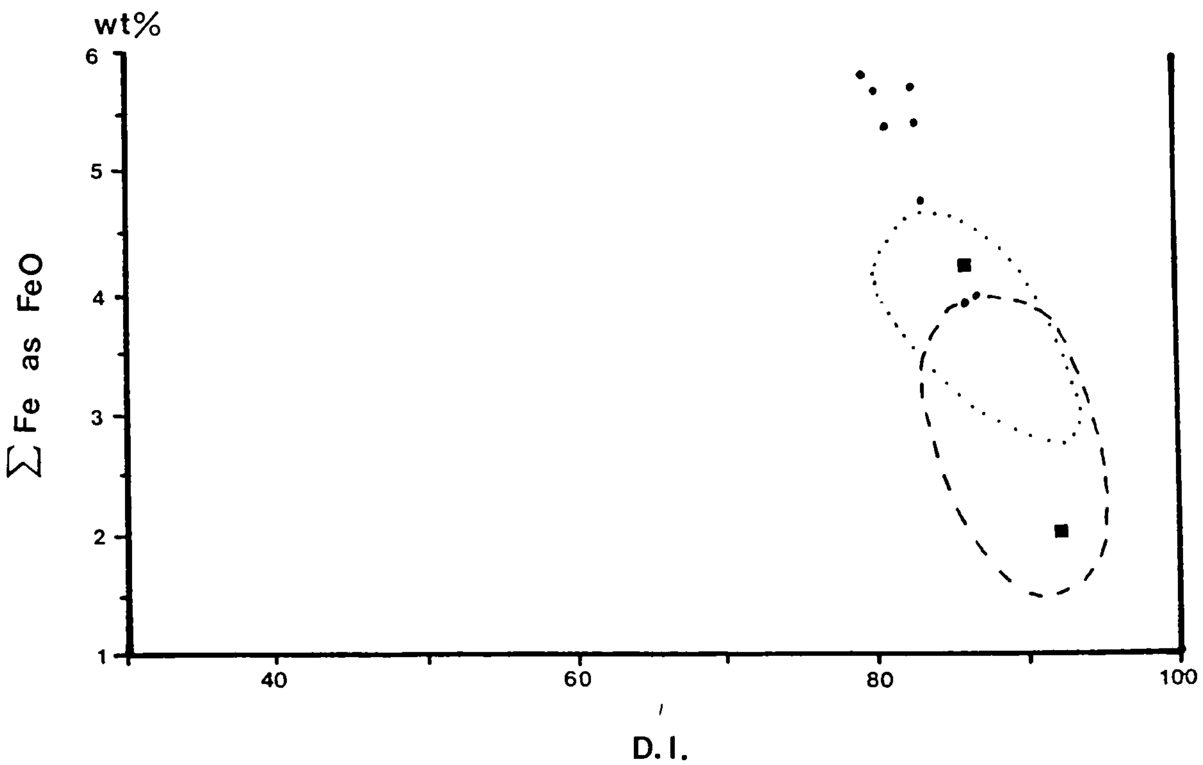

wt%
6
5
4
3
2
1
∑ Fe as FeO
40
60
80
100
D.I.

FIG. 4

4.3 TRACE ELEMENT GEOCHEMISTRY

Figure 4.9 of Sr-Rb data appears at first sight to show an apparent fractional crystallization trend with increasing values of Rb accompanied by decreasing Sr (McCarthy and Hasty, 1976). With the aid of petrographic and field observations this trend becomes misleading, as is illustrated by the removal of the points acquired from the contact zone. It would be incorrect to interpret these points as representing the crystallization of the Coe Hill granite proper as they have undergone contamination by the surrounding country rocks in this contact zone. With the deletion of these points two clusters, representative of the two heavily sampled quarries, with miscellaneous areas overlapping are all that remains. With these results it is difficult to infer any trend other than the granitoid proper is fairly constant with respect to Rb.

Figure 4.9 Trace element Sr-Rb diagram for the Coe Hill granite. Broken lines outline the position of Loon Lake pluton samples as in major element diagrams.

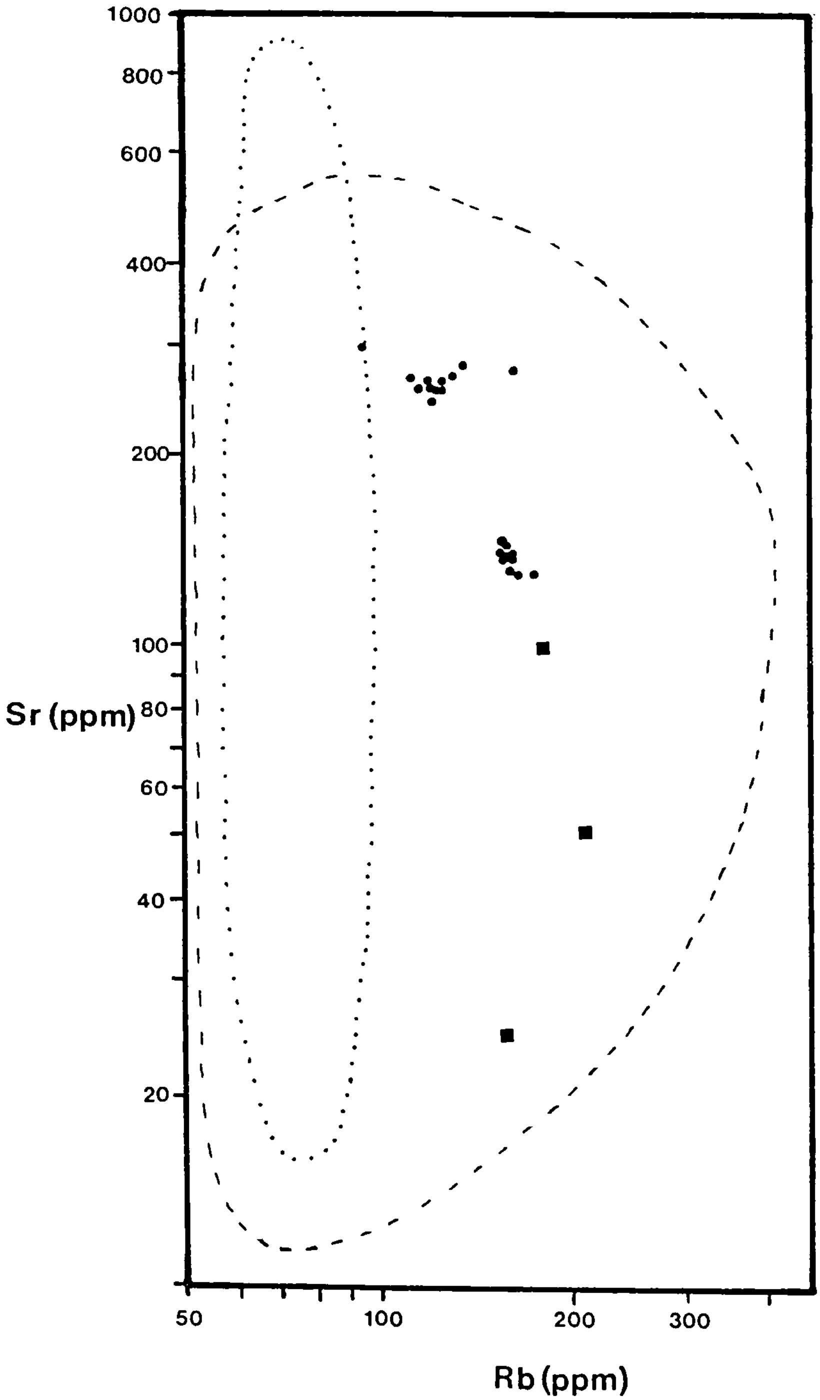


FIG. 4.9

CHAPTER 5

DISCUSSION

Through the synthesis of the data presented in this text, the available oxygen isotope data and the unpublished (pers. commun.) data of L. Heaman (acquired through the analysis of samples gathered for this study, amongst others), various inferences may be made regarding the age and origin of this granitoid pluton and its relation with similar plutons in the immediate area.

5.1 AGE OF THE COE HILL GRANITE

As mentioned in Chapter 3, the age acquired through Sr isotope analyses of samples most representative of the Coe Hill granite proper defines an event occurring at 1063 $\pm$ 21 M.a. This date, based upon consistently observed homogeneous petrographic, geochemical and field observations, has been interpreted as representing the age of emplacement of the pluton. Structurally the pluton is free of foliation (except along contact zones) and is conformable with the surrounding country rocks, but is independent of the regional fold pattern. Mineral and facies relations that would be indicative of a high grade of metamorphism, capable of disturbing the Rb-Sr systematics, are absent. These features, along with the regular character of the major element oxides, appear to signify that the rocks of the Coe Hill granite are representative of a post kinematic pluton emplaced at 1063 ± 21 M.a.

5.2 COMPARISONS BETWEEN SIMILAR GRANITOIDS IN THIS REGION

In order to determine whether the Coe Hill granite is related to similar granitoid plutons in the immediate area all of the available geochemical, petrographic and field data must be utilized in making comparisons. In a comparison between the Coe Hill granite and the Loon Lake pluton, quartz monzonite zone, petrographic, geochemical; including trace element Rb, Sr, Y and Zr, stable and radiometric isotope and major element oxide data are available. For the comparison between the Coe Hill granite and the Methuen granite a minor amount of data restricted to petrographic and field observations are all that is available.

5.2.1 Comparisons Between the Loon Lake Pluton and the Coe Hill Granite

The Coe Hill granite and the Loon Lake pluton lie adjacent to one another. These plutons are divided by a large swamp and in some locations are less than a kilometer apart (Fig. 1.3). Petrographically and texturally the quartz monzonite of the Loon Lake pluton (L.L.p.) is very similar to that of the Coe Hill granite. This similarity is illustrated through identical major and accessory minerals which display similar textures. The only significant differences that occur are in the mafics of the Coe Hill granite (C.H.g.) (predominantly biotite) as they are more abundant (average mafic content of 7 C.H.g. samples = 12.4% while average of 17 L.L.p. samples = 6.0%; Dostal, 1973).

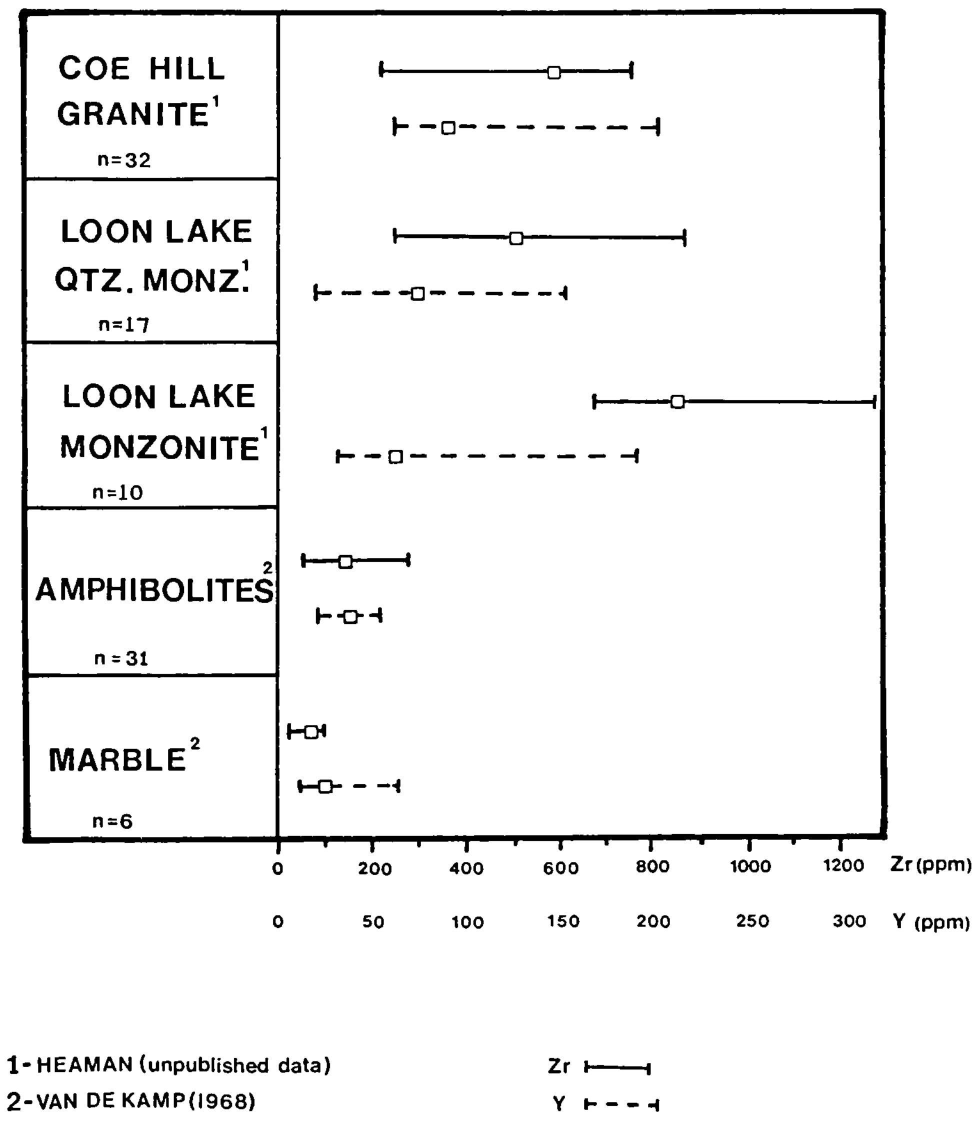
The effects of an increase in the mafic minerals is evident in the more basic value of the differentiation index (D.I.), visible in the samples of the Coe Hill granite (average D.I. = 83.7% while Nockolds' (1954) average D.I. for quartz monzonite = 91.4%) and the Loon Lake pluton quartz monzonite (average D.I. = 89.9%; Dostal, 1973). Major element oxide diagrams (Figs. 4.5, 4.6 and 4.8) reflect this increased mafic content by the enrichment in CaO, MgO and FeO relative to the Loon Lake quartz monzonites. Excepting these trends towards increased basicity the zones occupied by the other major element oxides of the two granitoids are very similar. Figures 4.1 to 4.4 illustrate how the quartz monzonites of both plutons occupy the same range in SiO_2, Al_2O_3, K_2O and Na_2O.

Along with petrographic and geochemical similarities some striking analogies are evident in the anomalous trace element values for these two quartz monzonite granitoids. Rubidium, a common element incorporated in potassium minerals such as K-feldspar and micas, generally increases with increased differentiation of the host rock and is at a maximum in the late stage potassium minerals (Heier and Billings, 1978). Hurley et al. (1962) (from Heier and Billings, 1978) compiled Rb abundances from 290 granite samples to acquire an average value of 196 ppm Rb. Comparison of Rb values for the two granitoids illustrates that both the Loon Lake quartz monzonite and the Coe Hill granite are normal to slightly low in Rb compared to this average yet are anomalously high in Rb compared to the more potassium rich Loon Lake monzonite (L.L.m.) (C.H.g. average Rb value for 32 samples = 144 ppm, L.L.q.m. average Rb value for 17 samples = 184 ppm and L.L.m. average Rb value for 10 samples = 63 ppm; Heaman et al., 1982). The enrichment of Rb in both of these quartz monzonites yields a very irregular array of points when plotted against strontium (Fig. 4.9), while the Loon Lake monzonite shows a strong fractional crystallization trend.

Further anomalous trends are displayed in trace elements Yttrium and Zirconium values for these two quartz monzonites. Yttrium is a trace element incorporated in a number of complex minerals of which allanite, present in these rocks, is most common. Figure 5.1 illustrates the relative abundance of this element with respect to many of the surrounding country rocks and the large range of values observed in these granitoids. These values are very similar for both the quartz monzonites and are generally higher than the average for granites in general (i.e. granite with 60-70%

Figure 5.1 Comparison of trace element Y and Zr compositions of monzonite and quartz monzonite samples from the Coe Hill granite and the Loon Lake pluton together with those of some of the other lithologies in this region.

FIG. 5.1


COE HILL GRANITE[1]
n=32
LOON LAKE QTZ. MONZ.[1]
n=17
LOON LAKE MONZONITE[1]
n=10
AMPHIBOLITES[2]
n = 31
MARBLE[2]
n=6
0 200 400 600 800 1000 1200 Zr (ppm)
0 50 100 150 200 250 300 Y (ppm)
1- HEAMAN (unpublished data)
2- VAN DE KAMP (1968)
Zr
Y

SiO has average Y = 43 ppm; Hermann, 1978).

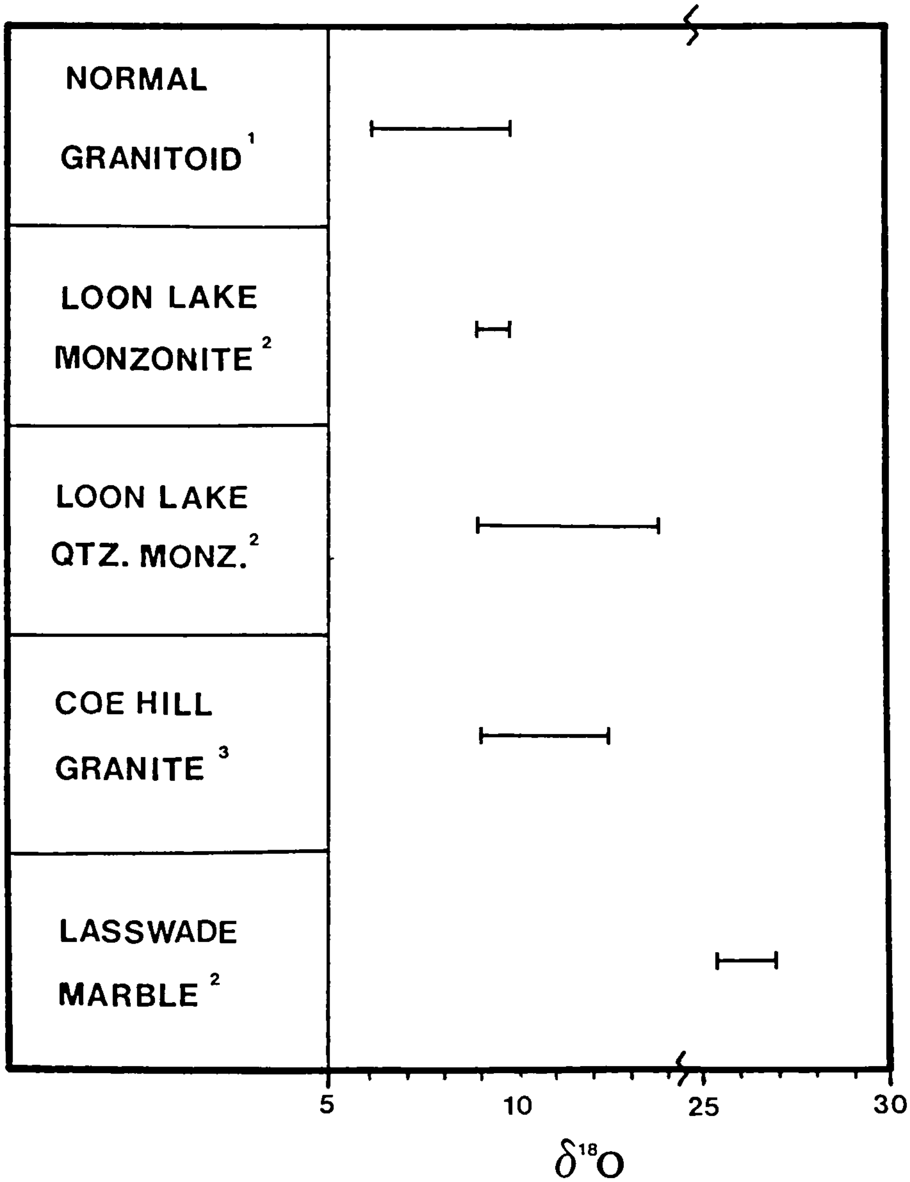
The silicate zircon has generally been found to exist as one of the most common accessory minerals in igneous rocks. In the Coe Hill granite zircon has been found as a common accessory mineral in biotite (Fig. 2.). Degenhardt (1957) (from Erlank et al., 1978) has shown that zirconium, in granites (as zircon), occurs with an average abundance of 175 ppm. Vinogradov (1962) (from Erlank et al., 1978) derived a slightly higher average of 210 ppm Zr. Again both the quartz monzonite bodies show similar ranges and mean values (Fig. 5.1) that are anomalously higher than the values commonly observed in similar rock types (mean value of Zr in C.H.g. = 585 ppm and mean value of Zr in L.L.p. = 509 ppm (Heaman et al., 1982).

The anomalous trends shared between the two quartz monzonite bodies is also observed in oxygen isotope data. Figure 5.2 compares the range of values from the Loon Lake pluton and the Coe Hill granite with values generally associated with normal granitoid rocks. Again the two quartz monzonites have anomalously high values compared to normal granitoids, showing an average 5 per mil heavier in $\delta^{18}O$.

As illustrated there are abundant similarities in the structural and stratigraphic features, petrographic, geochemical (including major and trace elements) and oxygen isotope data, along with virtually identical (within experimental error) ages and $^{87}Sr/^{86}Sr$ initial ratios, between the Coe Hill

Figure 5.2 Comparison of the oxygen isotope composition of monzonite and quartz monzonite samples from the Coe Hill granite and the Loon Lake pluton along with the field for normal granitic rocks and the Lasswade marble (surrounding country rock).

FIG. 5.2



1 - TAYLOR (1978)

2 - SHIEH et al. (1976)

3 - SHIEH (1980)

granite and the Loon Lake pluton composite (t=1065±13 Ma, R_i= 0.7034±4). Of these similarities the anomalous features are most striking. The only meaningful variation observed in the data presented in this thesis is the anomalous content of mafic minerals. Possible causes for this deviation may be a function of conditions occurring during the ascent and emplacement of these bodies. Although there are a number of possibilities for this it is certain that they are not a result of emplacement at different periods of time (due to geochronological evidence) and that they would probably not be a result of increased assimilation of the surrounding country rocks, as indicated by the low R_i found in these rocks (Chappell and White, 1974; Heaman, 1980; Brown, 1977). Possibilities for compositional variations could include different rates of upward movement of the magma body, either from anastomosing dykes from this body or as a rising diapir (Pitcher, 1978), geometrical relationships between the pluton and the surrounding country rocks (as emplacement on an angle forbids the observance of compositional changes with depth) and the possibility that these plutons stem from different dykes offshooting from the main magma body and thus have slight compositional variations. The present exposure of these bodies restricts any confirmation of these possibilities and promotes additional theories as to the cause of these variations.

The analogous trends observed between the recently acquired and available data of the two granitoids seems to suggest that these two quartz monzonite bodies are cogenetic and that slight variations could be the result of conditions occurring during their ascent and/or emplacement. Thus given the credible amount of identical and strikingly similar trends observed between these two granitoids a cogenetic nature is most probable. In order to aid in the confirmation or contradiction of this cogenetic theory additional work should include some rare earth, and other incompatible element, analyses on the Coe HIll granite. This would allow the comparison of the trends found in these elements with published data on the Loon Lake pluton (Dostal, 1973) and would provide some additional information on the origin of these granitoids.

5.2.2 Comparisons Between the Coe Hill and Methuen Granites

The Methuen granite is exposed as a curving crescent shaped pluton over 19 km in length with a maximum width of 6.4 km which occupies roughly 50 per cent of Methuen Township (Ontario Dept. of Mines Map Sheet 1960e). In the northeastern portion of Lake Township the Methuen granite necks and becomes the Coe Hill granite in Wollaston Township (Fig. 1.3). Unlike the Loon Lake - Coe Hill comparisons the data available on the Methuen granite is restricted to field observations of lithologic and structural features, and minor petrographic work,

The minerals and textures of the rocks of the Methuen granite are similar to those of the Coe Hill granite (Hewitt,

1960) yet the structural differences between these two granitoids and the surrounding country rocks show very few similarities. Structurally and lithologically the Methuen granite is composed of three main lithologic facies which include:

1. a pink biotite leucogranite which is foliated or lineated;
2. a fine grained grey biotite granodiorite, which occurs as inclusions in the pink granite;
3. a pink porphyritic facies of biotite granite (Hewitt, 1960).

All these facies are commonly foliated with lineations most commonly striking northeast-southwest, in agreement with the metasediments and intrusives, metamorphosed during the Grenville event. This pre-kinematic age is given further support by some geochronological Rb-Sr work yielding an age distinctly older than that of the Coe Hill granite and the Loon Lake pluton.

In light of this evidence which indicates the distinctive features of these granitoid bodies it would be appropriate for future research to concentrate on a detailed mapping and sampling of the neck area of the Methuen granite in an attempt to locate the transitional stages between the two granitoids. Future work could also include geochemical, trace element and rare earth element studies in order to investigate similarities or differences in the possible source of these two granitoids as has been done in this study for the Coe Hill granite and the Loon Lake quartz monzonite.

5.3 ORIGIN OF THE COE HILL GRANITE

In order to determine the origin of a suite of plutonic rocks it is necessary to utilize as much geochemical, petrographic and field data as is available. Hine et al. (1978), Pitcher (1978) and Chappell and White (1978), amongst others, have made use of a systematic approach first proposed by Chappell and White (1974) to identify the source of Paleozoic plutons from Australia. This system utilizes a number of chemical and physical characteristics to differentiate between granitoids derived from a sedimentary precursor (S-type) and those derived from an igneous source (I-type). Table 5.1 is a comparison of the common characteristics used to define Chappell and White's S- and I-type granites with those found in the rocks of the Coe Hill granite. This comparison illustrates the overwhelming predilection supportive of an I-type, or igneous, origin.

Exceptions to this classification occur in the anomalously high $\delta^{18}O$ value. Shieh et al. (1976) has postulated that an H_2O- or CO_2-rich fluid phase derived from the country rocks interacted with the outer portion of the Loon Lake pluton (i.e. the Loon Lake quartz monzonite) and that this could be responsible for the variable and anomalously high $\delta^{18}O$ value. This hypothesis is appealing as:

TABLE 5.1

The Coe Hill Granite with Respect to S- and I-type Granitoids

% Na_2O	<2.2%	>2.2%	>2.2%
Molar $Al_2O_3/(Na_2O+K_2O+CaO)$	>1.1	<1.1	<1.1[1]
C.I.P.W. normative corundum	>1%	<1%	<1%
Variation diagrams	irregular	regular	both
Mafic minerals	musc,bio(up to 35%) gt,cd	bio,hbld	bio,hbld
Accessory minerals	mon,il,sph	sph,ap,mt	sph,ap
Xenoliths	rare, metasedimentary	mafic bearing	mafic bearing
Composition	restricted, high SiO_2 type	varied, felsic to mafic	varied, felsic to mafic
R_i	0.708	0.704-0.706	0.704
$\delta^{18}O$	15%	5-10%	9.0-12.5%[2]

[1] refer to Fig. 5.3
[2] Shieh (1980)

Abbreviations for Table 5.1
mon-monzonite, musc-muscovite, bio-biotite, hbld-hornblende, il-ilmenite
sph-sphene, ap-apatite, mt-magnetite, gt-garnet, cd-cordierite

Figure 5.3 Variation in molar $Al_2O_3/(Na_2O+CaO+K_2O)$ as a function of D.I.

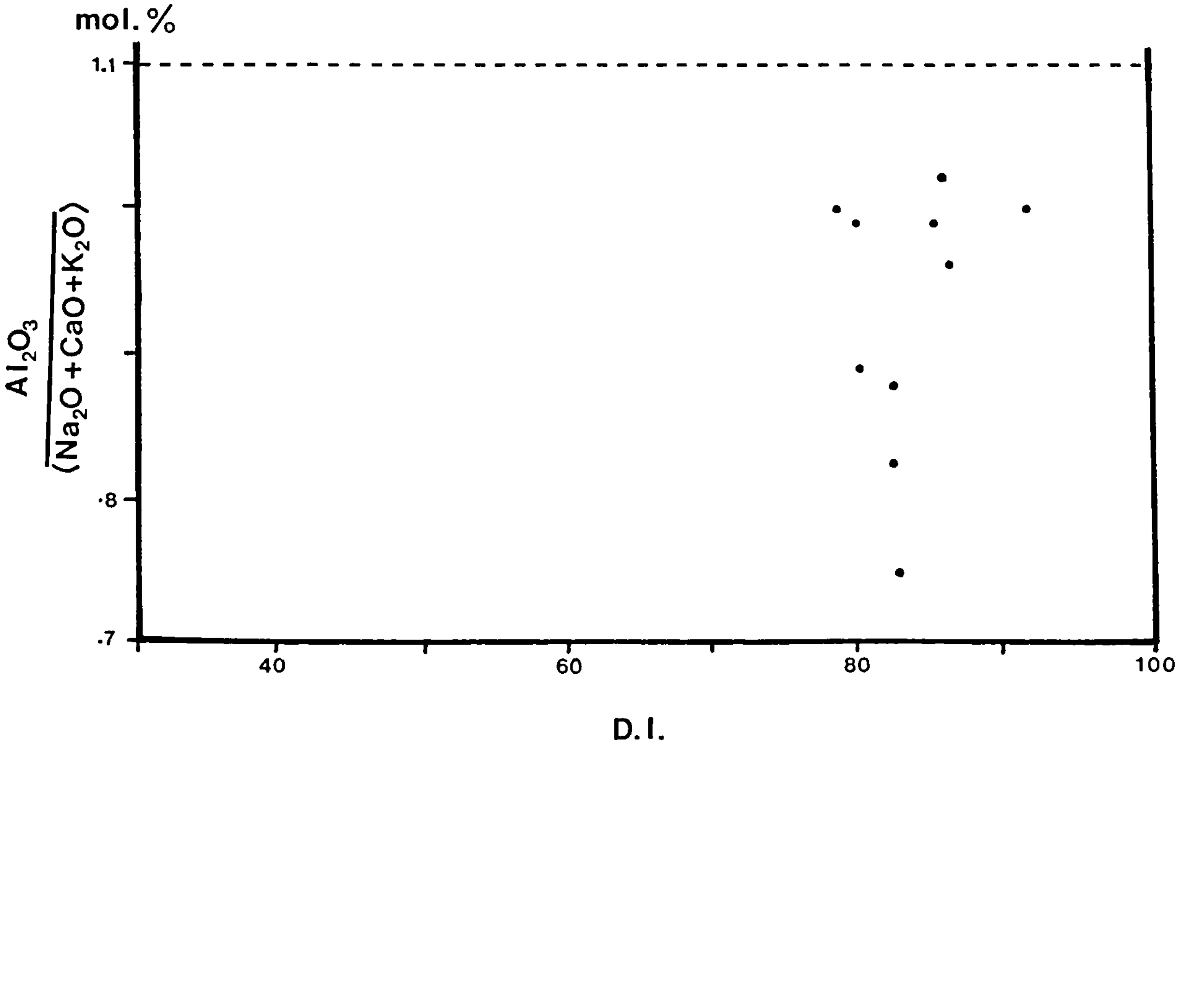


FIG. 5.3

1. it may also explain the enrichment in SiO_2 and incompatible elements such as Rb in the outer zone of the Loon Lake pluton (quartz monzonite zone), and similarily in the Coe Hill granite;
2. the surrounding country rocks are extremely enriched in $\delta^{18}O$ values (Fig. 5.2);
3. possible alternative methods such as assimilation of xenoliths and mixing of magma with anatextic mobilisates (suggested by Shieh, 1976) are very unlikely to occur without significantly increasing the $^{87}Sr/^{86}Sr$ initial ratio and this has not been done as R_i = 0.7040 ± 5 for the Coe Hill granite.

It must be noted that special care must be taken when using Chappell and White's (1974) classification in these rocks as acceptance for this model has not been extended into applications of Proterozoic age rocks and because the classification boundaries outlined in Table 5.1 are not necessarily absolute (as was found by Flood and Shaw, 1977). With these factors taken into account this model still acts as a good catalogue for allocating certain features generally found to be consistent with a particular origin.

Therefore, through the observance of the characteristics outlined in Chappel and White's (1974) classification and the supposition of a cogenetic relationship between the Coe Hill granite and the Loon Lake quartz monzonite it would appear that these granitoids are of an igneous origin, that they may not be mantle derived but rather from a lower crustal origin or at least reacted with the lower crust (high $\delta^{18}O$ yet low R_i) and that they were emplaced after the main Grenville metamorphic event, at 1063 ± 21 Ma.

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APPENDIX A

A.1 ANALYTICAL PROCEDURE FOR GEOCHEMICAL ANALYSES

Samples that appeared to be most representative of the Coe Hill granite proper were collected throughout the pluton. These samples were acquired from outcrops, or areas of outcrops that were visibly devoid of dykes, xenoliths and extreme weathering or fracturing. Heterogeneous looking samples (found in the contact gneissic zone) were also collected in order to observe variations between the Coe Hill granite proper and these heterogeneous localities in the pluton.

Sample preparation consisted of breaking off any weathered portion of the samples prior to their crushing. One third of each 5 to 15 kg sample was retained for a hand specimen and thin sectioning. The remainder of each sample was put through a three stage pulverizing process that included:

1. Jaw Crusher - where field samples were reduced to 2 to 4 cm^3 fragments;
2. Ceramic Disc Grinder - where fragments from the jaw crusher were further reduced to 1 cm^3 fragments;
3. Tungsten-Carbide Grinder - where fragments from the ceramic disc grinder were further reduced to

a very fine powder.

The fine powder from each sample was stored in a fresh 250 ml polypropylene container. After each sample had been through this pulverizing process all equipment underwent a thorough cleaning. This includes the scraping of all metal parts with a wire brush, followed by high pressure air cleaning and an acetone rinse, of all pieces of equipment by the next sample to be crushed.

In preparation for the analysis of major element oxides 0.5 gm of this fine powder was mixed with 3 gm of a 1:1 mixture of lithium metaborate-lithium tetraborate compound in a clean 5 gm glass vial. This mixture was loaded into a platinum crucible and heated until it was liquid, which was then cast as a 3 cm diameter shallow disc, left to cool to a glass and was removed. Each glass disc was analysed at the McMaster University XRF laboratory using a Phillips PW 1450 automated XRF.

Preparation for the Rb and Sr analyses required that 3 to 4 gms of the same fine powder be mixed with 3 drops of Mowiol binding solution in a 5 gm glass vial. This mixture was loaded evenly onto a Chemplex aluminum pellet cup whereupon it was compressed under 20 tons of pressure in a Spex 30 ton press. Each compressed powder pellet was also analysed at the McMaster XRF laboratory.

The results of the major element geochemical analysis and C.I.P.W. normative values, derived from this data (method of C.I.P.W. calculations from Shaw, 1978) are given in Table A.1 while Rb and Sr results are given in Table A.2. Evaluation of the error associated with this analysis is similar to the method performed on Rb and Sr analysed by XRF (Appendix B).

TABLE A.1

Major Element Geochemical Analysis of Coe Hill Granite (in wt. %)

TACH	1	2	3	8	13	15	18	21	24	32
SiO_2	66.11	63.87	66.68	66.71	66.98	74.15	72.36	70.06	69.77	64.44
TiO_2	0.91	0.92	0.88	0.93	0.88	0.17	0.28	0.46	0.50	0.97
Al_2O_3	14.33	14.24	15.03	14.50	14.40	13.23	12.36	13.92	13.03	14.34
Fe_2O_3	0.54	0.47	0.57	0.58	0.54	0.22	0.42	0.38	0.40	0.57
FeO	4.85	4.28	5.12	5.19	4.82	1.94	3.79	3.45	3.59	5.16
MnO	0.09	0.06	0.09	0.11	0.11	0.03	0.07	0.07	0.08	0.11
MgO	1.52	3.67	1.12	1.41	1.30	0.71	1.76	1.62	1.14	2.00
CaO	2.20	1.55	2.09	2.36	2.27	0.89	1.27	1.24	1.54	2.29
Na_2O	4.20	5.97	3.08	2.84	4.14	4.04	3.30	3.64	3.82	4.94
K_2O	4.99	5.73	5.09	5.08	4.81	4.55	4.36	5.04	5.12	4.84
P_2O_5	0.26	0.27	0.27	0.30	0.26	0.08	0.03	1.10	0.11	0.34
Total	100	100	100	100	100	100	100	100	100	100
Q	15.2	6.9	21.3	22.4	15.0	28.3	29.2	23.2	21.5	10.0
Or	29.6	33.0	30.6	30.5	28.3	27.0	26.1	30.0	30.5	28.5
Ab	37.8	43.0	28.1	25.9	37.0	36.4	30.0	32.8	34.5	44.0
An	5.5	--	9.6	9.9	6.4	3.9	6.1	5.5	5.7	2.6
Cor	--	--	1.1	0.8	--	0.2	--	0.5	--	--
Di	3.0	4.7	--	--	6.0	--	0.1	--	1.0	5.2
Hy	6.4	7.6	7.2	7.8	4.8	3.4	7.6	6.7	5.5	6.9
Mt	0.6	--	0.6	0.6	0.6	0.2	0.5	0.4	0.4	0.6
Il	1.3	1.3	1.2	1.3	1.2	0.2	0.4	0.6	0.7	1.3
Ap	0.6	0.6	0.3	0.6	0.65	0.2	0.1	0.2	0.2	0.7
Acm	--	1.3	--	--	--	--	--	--	--	--

TABLE A.2

Trace Element Geochemical Analysis of Coe Hill Granite
(values in ppm)

Sample	Rb	Sr	Sample	Rb	Sr
TACH 1	127.5	278.7	TACH 17	179.3	101.5
2	158.5	284.6	18	158.4	25.1
3	91.0	309.2	19	157.8	140.2
4	119.6	262.6	20	159.4	145.8
5	117.7	251.3	21	157.1	146.8
6	116.5	262.9	22	156.1	143.6
7	116.0	272.8	23	152.4	145.6
8	121.7	259.3	24	157.6	141.1
9	120.0	264.8	25	155.8	149.5
10	114.8	260.6	26	153.7	141.5
11	122.1	273.5	27	161.3	136.5
12	117.3	266.8	28	159.3	137.8
13	107.9	274.5	29	171.2	134.7
14	111.6	264.6	30	153.2	150.7
15	210.1	52.3	31	159.0	143.6
			32	130.8	287.1
			33	155.3	146.2

APPENDIX B

B.1 ANALYTICAL PROCEDURES FOR STRONTIUM ISOTOPE ANALYSES

The sampling techniques for isotope analyses are similar to those for the geochemistry in that samples intended for the analysis of the Coe Hill granite proper must be acquired from homogeneous-looking samples. Samples from heterogeneous areas were also sampled to illustrate the variation in these areas and how they may have affected the Rb-Sr systematics.

Preparation of samples for geochronology and the procedure for analyses of Rb and Sr by x-ray fluorescence spectroscopy is similar to the procedure outlined for geochemical analyses. This preliminary analysis of Rb and Sr provided data for the selection of the initial twelve samples for isotopic analyses. Triplicate powder pellets were prepared for each of the samples selected. These pellets were analysed for Rb and Sr concentrations by XRF spectroscopy following the method outlined by Turek et al. (1977). The samples to be analysed for isotopic concentrations were prepared for strontium isolation following the method outlined by Beakhouse and Heaman (1980). The product of this isolation procedure, a clear to white dry film of strontium at the bottom of a Vycov beaker, was made into a solution by the addition of a single drop of double distilled H_2O, using a disposable pipette. The drop was applied to a preconditioned

.03 by .001 mm tantalum filament, etched with a single drop of 1.0 M H_3PO_4. Three drops of the strontium solution were applied to the tantalum filament, allowing each drop to dry before successive drops were dispensed. The filament bearing buttons were loaded into the single filament, 10 inch, 90^o sector, Nier-type mass spectrometer according to the procedure outlined by Wolff (1977a). A description of the operating conditions and techniques, including modifications by L.M. Heaman, are given by Heaman (1980).

B.2 ANALYTICAL ERRORS

The methods used to decipher the analytical error follow the rigorous work performed by Heaman (1980). Basically these entail the evaluation of error through the determination of the accuracy of the analyses, acquired through the analysis of known accepted standards (Eimer and Amend $SrCO_3$ standard for mass spectrometry, and U.S.G.S. standards G-2 and GSP-1 for XRF) and the ability to reproduce similar isotopic values from samples analysed in duplicate, or triplicate, on the mass spectrometer and by XRF respectively. Heaman (1980) has assigned a blanket error of ± 1.0% to the regression model for all Rb/Sr ratios from XRF analyses. The accuracy of the isotopic analyses performed on the Eimer and Amend $SrCO_3$ standard, during the period of which the samples for this study were analysed, is given in Table B.1. The determination of how close the mean of these analyses are to the known value of this standard (.70800) provides an indication as to the accuracy of the analyses performed and enables adjustments to be made according to these variations. Reproducibility of the isotope analyses is shown by the analyses of duplicates (Table B.2). Heaman (1980) noted an average error of ± 0.02% and assigned this value as a blanket error for all whole rock Sr isotopic ratios. This value is acceptable for the analyses performed on the Coe Hill granite duplicate.

A rigorous method is used to analyse the isochron errors, in order to determine whether the array of points on a $^{87}Sr/^{86}Sr$ versus $^{87}Rb/^{86}Sr$ diagram actually represents the time of the geologic event responsible for these rocks. The method used in this study is outlined in Heaman (1980) from Brooks et al. (1972) and utilizes Brooks' York II model in the calculation of isochron errors.

TABLE B.1

Accuracy of the Sr Isotope Analyses on E + A Standard*

Date	Operator	$^{87}Sr/^{86}Sr$	$\sigma_1 x 10^{-4}$	Peak Scans
Nov. 21/82	T.A.	.708336	0.6097	110
Dec. 9/82	L.H.	.708205	0.3591	170
Dec. 30/82	T.A.	.708299	1.4729	60
Dec. 30/82	T.A.	.707375	3.4256	90
Jan. 5/83	K.C.	.708054	1.5372	140
Jan. 8/83	K.C.	.708166	2.3---	180
	mean	0.708240		

*E + A published $^{87}Sr/^{86}Sr$ value = 0.70800

$$\sigma_1 = \left[\frac{\Sigma(x-\bar{x})^2}{N(N-1)}\right]^{1/2}$$

where x = $^{87}Sr/^{86}Sr$ value for 10 peak scans
$\bar{x}$ = mean value of $^{87}Sr/^{86}Sr$ values used in σ_1 calculated
N = number of 10 peak scans used in error calculation

T.A. = Tom Atkins
L.H. = Larry Heaman
K.C. = Kevin Connare

TABLE B.2

Duplicate Analysed on the Mass Spectrometer

Sample	Date	$^{87}Sr/^{86}Sr$	Scans	$^{87}Sr/^{86}Sr$	% Error*
TACH30	Nov. 8/82	.74649	130	.74657	.011
TACH30	Dec. 29/82	.74665	80		

*% error calculated from $\{[(x - x)/2]/\bar{x}\}$ x 100 (Heaman, 1980)

ADDENDUM

The $^{87}Rb/^{86}Sr$ ratios used in calculating the age of the Coe Hill granite in this thesis were not corrected for the appropriate proportion of ^{86}Sr in the samples. In Table C.1 the $^{87}Rb/^{86}Sr$ ratios are corrected using the following equation:

$$^{87}Rb/^{86}Sr = \left[\frac{Ab^{87}Rb \times Awt.\ Sr}{Ab^{86}Sr \times Awt.\ Rb}\right] \times \left[\frac{Rb}{Sr}\right] wt.$$

where Ab. = Abundance of a particular isotope

Awt. = Atomic weight

wt. = Weight ratio obtained from XRF

Using the corrected $^{87}Rb/^{86}Sr$ ratios changes the age calculation slightly. The revised age and initial strontium ratio for the Coe Hill pluton are $t = 1034 \pm 20$ Ma. and $R_i = 0.7040 \pm 6$, respectively.

TABLE C1. Rb and Sr concentrations and Sr isotope composition for samples from the Coe Hill pluton

	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr^{a}$
<u>Massive Samples</u>					
TACH 2	161	287	0.5618	1.6296	0.72779 ± 0.00007
TACH 3	92.9	308	0.3014	0.8733	0.71692 ± 0.00014
TACH 8	123	258	0.4755	1.3788	0.72420 ± 0.00026
TACH 13	109	276	0.3971	1.1511	0.72128 ± 0.00006
TACH 21	154	150	1.0277	2.9874	0.74990 ± 0.00008
TACH 24	157	143	1.0984	3.1933	0.75110 ± 0.00008
TACH 27	165	140	1.1767	3.4222	0.75472 ± 0.00009
TACH 28	156	139	1.1260	3.2739	0.75205 ± 0.00007
TACH 30	155	155	1.0018	2.9112	0.74645 ± 0.00002
<u>Contaminated Samples</u>					
TACH 15	212	57.5	3.6834	10.8853	0.89234 ± 0.00011
CH 1	204	272	0.7511	2.1855	0.75971 ± 0.00010
CH 2	189	57.2	3.2993	9.6989	0.86561 ± 0.00022
CH 3	201	57.6	3.4881	10.2615	0.87329 ± 0.00019
CH 4	164	56.9	2.8836	8.4589	0.84366 ± 0.00010

a $^{87}Sr/^{86}Sr$ ratios normalized to $^{86}Sr/^{88}Sr = 0.1194$