METAMORPHISM IN THE GEORGE RIVER GROUP CAPE BRETON ISLAND, NOVA SCOTIA

METAMORPHISM IN

THE GEORGE RIVER GROUP

CAPE BRETON ISLAND, NOVA SCOTIA.

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CHRISTOPHER RAYMOND DAVIS

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HONOURS BACHELOR OF SCIENCE (1983) (Geology) TITLE: Metamorphism in the George River Group Cape Breton Island, Nova Scotia AUTHOR: Christopher Raymond Davis SUPERVISOR: Professor B.J. Burley NUMBER OF PAGES: viii, 112 ABSTRACT:

A sequence of metasedimentary rocks comprising the George River Group, Cape Breton Island, Nova Scotia, was studied. A petrographic examination of the five different rock types present -- marbles, amphibolites, paragneisses, skarn xenoliths, and granitic bodies was carried out. A petrochemical analysis, using X.R.F. methods was also completed.

The GRG has undergone three distinct periods of metamorphism. The first was a period of kyanite grade regional metamorphism, believed related to the Grenville orogeny. High grade metamorphic minerals developed in the various lithologies present in the GRG. These minerals were kyanite, diopside, forsterite, hornblende, and muscovite.

A chlorite grade regional metamorphism followed, creating such low grade minerals as chlorite, sericite, and serpentine. These minerals formed by the hydrolysis of higher grade metamorphic minerals.

Following this low grade metamorphism, the GRG was

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subjected to a period of wollastonite grade contact metamorphism. This metamorphic period resulted from the injection of smaller granitic bodies believed related to the Acadian orogeny. The formation of contact metamorphic minerals such as, wollastonite, vesuvianite, phlogopite and sphene characterize the assemblages formed by this metamorphic event.

The petrochemical analysis shows that these metasedimentary GRG rocks had protoliths of several types, including siliceous dolomitic limestones, siliceous limestones, greywackes, and basic volcanic sills. The amphibolites present crossing the GRG formed by the metamorphism of the basic volcanic sills.

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CHAPTER 1: INTRODUCTION

I) Statement of Problem:

The George River Group (GRG) metasedimentary rocks are believed to be Precambrian in depositional age (1400-1700 my.). A deformation, and metamorphic event, broadly contemporaneous with the Grenville orogeny (900-1000 my.) occurred, and metamorphosed this metasedimentary group for the first time. Since that time, the Acadian orogeny, an event the result of continental collision during plate convergence (Naylor 1971) occurred and metamorphosed the GRG for the second time. The metamorphic grade of these rocks is believed to be of sillimanite grade, but detailed work in this field has not been attempted.

The aim of this study is to determine the metamorphic history of a part of the metasedimentary rocks of the GRG by examining a representative suite of the group, with emphasis being placed on its petrography and petrochemistry.

II) Location and Accessibility:

The bypass tunnel of this study is approximately 15 kms west of Wreck Cove, and 2.5 kms northeast of McMillan Flowage in Victoria County, Northeastern Cape Breton Island (Figure 1, derived from Department of Energy, Mines and Resources, 1981).

Figure 1: Location Map.

(derived from Department of Energy, Mines and Resources, 1981).



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The study area, and bypass tunnel can be reached easily and directly from all areas in Cape Breton Island. Permission is required from the Nova Scotia Department of Mines and Energy in order to travel the lumber roads found crossing the Cape Breton Highlands and study area.

III) Previous Work:

The first recorded geological work in this area was in 1865 when gold was prospected for in the metavolcanic Fourchu Group. Between 1876 and 1884, Hugh Fletcher of the Geological Survey of Canada mapped all areas in Cape Breton Island that contained George River Group rocks. In 1956, A.S. MacLaren (GSC) mapped this area on a 1 inch to 1 mile scale. This map was very general, and failed to locate the GRG rocks in the study area, instead, the area was mapped as a composite gneiss. Since that time, the G.S.C. has continued work and has remapped the area. This mapping sparked the interests of three geologists, G.C. Milligan, R.A. Weibe, and A.K. Chatterjee.

G.C. Milligan (Nova Scotia Department of Mines, 1970) completed a detailed and systematic investigation of the GRG in central and western Cape Breton Island. His work was an extensive petrographic, structural and economic analysis of George River metasedimentary rocks in various locations around Cape Breton Island.

R.A. Weibe studied the Precambrian basement rocks

(1973), origins and emplacements of the Acadian granites (1972), and the differentiation in the layered diorites in the Ingonish area (1974).

A.K. Chatterjee (Nova Scotia Department of Mines) has been interested in the possibilities of base metal deposits occurring in the GRG. The sequence was studied for potential tungsten, copper, and zinc deposits. The work by Chatterjee has interested many companies, and has initiated the exploration for base metal occurrences in this study area.

IV) Regional Geology:

The geology of Northeastern Cape Breton Island is characterized by two structurally and compositionally distinct metamorphic units, and extensive igneous rocks, eg., Precambrian diorite plutons and Silurian to Devonian granitic rocks (Figure 2, derived from J.D. Keppie, 1979).

This sequence of metamorphic and igneous rocks is then unconformably overlain by Mississippian sediments, and cut by steeply dipping faults, eg., the Aspy fault which divides northern Cape Breton Island into northeastern and northwestern halves.

The oldest metamorphic unit is the George River Group, 1400-1700 my. It is a metasedimentary unit which includes unfossiliferous marbles, quartzites, and pelitic rocks. Amphibolitic layers are seen discordant to the bed-

Figure 2: Regional Geology.

The locations of the five Precambrian diorite plutons, and the Silurian to Devonian aged granitic bodies in relation to the GRG are shown (derived from J.D. Keppie, 1979).



ding and are probably metamorphosed basic dikes. Two sets of major folds, an older Precambrian, unit restricted set, and a younger Silurian set are evident in the GRG (Wiebe, 1972).

Overlying the GRG is the metavolcanic Fourchu Group, 560 my. The Fourchu Group consists of metamorphosed, and deformed felsic to intermediate volcanic, and volcaniclastic rocks. The younger Silurian folding set is clearly evident in this metavolcanic unit.

The plutonic rocks of Northeastern Cape Breton Island can be divided into two distinct groups; those emplaced before, and deformed by the Silurian-Devonian orogeny (Acadian), and those emplaced during and after this same orogeny. Important in Northeastern Cape Breton Island are five older aged plutons, and one suite of younger granitic rocks. These older plutons include the:

I) Glasgow Brook Pluton

II) Coastal Gneisses

III) Cape Smokey Pluton

IV) Cameron Brook Pluton

V) Ingonish River Pluton

The Ingonish River quartz-biotite-hornblende diorite and tonalite is the most important pluton in the study area due to the fact that it is in contact with, and often intrudes the marbles and other metasedimentary units within the GRG, but not the Fourchu Group.

The younger granitic rocks of the region are composed of leucocratic, fine to medium grained granodiorite and adamellite, which may be found as very large to small plutons. Towards the west of Cape Breton Island, these granitic bodies invade the older metamophic rocks. The contacts are irregular, nearly concordant, and suggestive of flow and folding of the metamorphics with granitic injection. These granitic bodies are believed to have been emplaced partly during, but mostly after the last major deformation, 410+50 my. (Wiebe, 1972).

Table 1 (Wiebe, 1972) is a summary of the geological events, with their probable ages for Northeastern Cape Breton Island. Depending of the location, the GRG has undergone at least two metamorphisms. The first occurred in association with the emplacement of the older plutons, and resulted in a high grade regional metamorphism. The second is related to the intrusion of the younger granitic rocks, and resulted in a contact metamorphism occurring on these already regionally metamorphosed sediments.

V) Local-Detail Geology:

Within a bypass tunnel excavated in 1976, the George River metasedimentary Group outcrops. The bypass tunnel is 110 metres long, trending 283/037. The GRG units outcrop with an orientation of 045/086 E (Figures 3,4,5).

The five basic rock types mapped along the bypass

Age	Surficial accumulation	Orogenic events	Intrusive events
410 my			Younger granitic rocks
		Major (Silurian) folding (Acadian Orogeny)	
			Cape Smokey Pluton
560 my	Fourchu Group(?)		Cameron Brook Pluton and coastal gneisses
		Unconformity	
(?)			Ingonish River Pluton
900-1000 my	r(?)	Major folding	(?)Glasgow Brook Pluton
1400-1700 m	my(?) George River Group(?)	(Grenville Orogeny)	

TABLE 1 SUMMARY OF EVENTS IN NORTHEASTERN CAPE BRETON ISLAND, NOVA SCOTIA

Figure 3: Looking east, up the excavated by-pass tunnel. The study outcrop is clearly visible along the length of the by-pass tunnel.

Figure 4: Looking west, down the bypass tunnel from a position within the tunnel. A lumber road is seen in the background.



Figure 5: Looking east up the bypass tunnel, showing the entire study outcrop.



tunnel are marbles, paragneisses, amphibolites, skarn xenoliths, and granitic bodies. Definite interbedding of the marbles and paragneisses, with amphibolitic sills is seen along the entire length of the bypass tunnel, with a granitic body intruding the sequence at the eastern portion of the outcrop. Minor felsic dikes are seen in locations along the interbedded metasedimentary sequence. These felsic dikes are believed to be associated with the emplacement of the Silurian to Devonian granitic rocks.

Refer to Figure 6 for a detailed schematic map of the GRG in this bypass tunnel.

VI) Method of Sampling:

To obtain a representative suite of the GRG, samples were taken from two to three locations within each mapable unit. This would allow observation of any changes within each unit. These samples were then integrated to provide a lithology of each unit present in the outcrop.

Figure 6: Detailed schematic map of the GRG in this bypass tunnel.

DETAILED OUTCROP MAP



LEGEND

W





Scale

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CHAPTER #2: PETROLOGY

A petrographic analysis of the study outcrop was undertaken. Both petrographic descriptions and accompanying sketches appear in Appendix A. The sample locations are plotted on Figure 17. The metamorphic minerals present are summarized in Table 2 and Table 3.

I) Marbles:

Samples examined from the marble units were CDS-2B, 11, 14A, 16C, and CDS-5. There are three distinctively different marble mineral assemblages in the study outcrop.

- 1) calcite + serpentine + phlogopite
- 2) calcite + serpentine + diopside
- 3) calcite + quartz + vesuvianite + diopside

+ wollastonite

1) Calcite + serpentine + phlogopite.

Grain sizes in this assemblage vary from <.1mm to 1mm. The grains are generally xenoblastic which yield a distinctive sutured texture. Calcite dominates the samples both in abundance and in size. The other minerals present occur as much smaller xenoblasts set in the calcite matrix, or groundmass.

The phlogopite occurs as small idioblasts that show a poikiloblastic, and symplectite texture with the calcite.

	TABLE #2:		TABLE	OF	METAMO	RPHIC	MIN	ERALS	
	QU ART Z	CALCITE	PHL0G0PITE	DI OPS I DE	VESUVIANITE	FORSTERITE	WOLLASTONITE	SERPENTINE	S PHENE
MARBLES	•								
CDS-2B		*		*				*	
CDS-11		*	*					*	
CDS-14A	*	*	*			*		*	
CDS-160	*	*	*					*	
CDS-5	*	*		*	*		*		*

CDS-19	CDS-23	GRANITIC BODIES	CDS-2C	CDS-3A	XENOLITHS	CDS-6B	CDS-24I	CDS-200	CDS-18	PARAGNEIS	CDS-15	CDS-13	AMPHIBOLI	
*	*		*	*	101	*	*	*	*	S ES	*	*	TES	QU ART Z
*				*			,_ <u>.</u>	*						CALCITE
											*			DIOPSIDE
				*										FORSTERITE
											*	*		HORNBLENDE
	*					*	*	*	*	_	*	*		BIOTITE
*	*		*			*	*	*	*		*	*		MUSCOVITE
*	*					*	*	*	*		*	*		AB PLAGIOCLASE AN
*	*		*											ORTHOCLASE
			*	*			*							MICROCLINE
						*	*	*	*					KYANITE
	*		*	*		*	*				*	*		SPHENE
*	*		*			*			*					CHLORITE
*		nangang a ngang , an angang ng		*										SERPENTINE
			*											TREMOLITE
			*											VESUVIANITE

TABLE #3: TABLE OF METAMORPHIC MINERALS

It shows no alteration, and appears to be very fresh as compared to the other minerals present. The only possible alteration may be the result of strain, which has developed twins in the phlogopite idioblasts.

The calcite shows strong evidence for a period of recrystallization. Cores, or poikiloblasts of calcite are found within larger calcite xenoblasts.

Antigorite serpentine is commonly found as isolated, fibrous xenoblasts or as aggregates (Figure ?). In most cases, the serpentine has completely replaced the parent mineral, but there are cases where forsterite can be seen between the serpentine fibres. This suggests that the serpentine is the result of hydrothermal alteration of the once present forsterite. In the case of CDS-16C, there are two varieties of serpentine. One variety occurs as fibrous aggregates, and the second occurs as tabular idioblasts. Both appear to have formed by the alteration of the forsterite xenoblasts.

2) Calcite + serpentine + diopside

Grain sizes in this assemblage range from the smaller <.1mm diopside xenoblasts to the larger .4mm calcite xenoblasts. The calcite comprises 80-90% of the assemblage, while the diopside and serpentine xenoblasts account for the remaining 20%.

Diopside occurs as small, rounded xenoblasts that are only partially altered to serpentine, while the calcite has a distinctive brown tinge associated with it (Figure 8).

Figure 7: Antigorite-serpentine present as isolated, fibrous xenoblasts or as aggregates. Mag. 125X

Figure 8: Diopside xenoblasts partially altered to serpentine. The calcite has a distinct brown tinge. Mag. 125X



This colour is the result of percolating serpentine rich fluids.

This assemblage shows strong evidence of both deformation and recrystallization. Calcite laminae are commonly bent, and curved indicating strain due to deformation. The calcite xenoblasts also contain poikiloblasts of calcite that are the result of a period of recrystallization.

3) Calcite + quartz + vesuvianite + diopside + wollastonite

Grain sizes in this assemblage vary from <.1mm to 2mm. The grains are predominantly subidioblastic to xenoblastic, with calcite being the most dominant mineral. The calcite is xenoblastic and comprises the groundmass in which the other minerals in this assemblage sit.

The vesuvianite is present as large (up to 2mm in size) xenoblasts that cross cut the other minerals. The minor wollastonite present, occurs as long (1mm) fibrous aggregates that seem to radiate from quartz xenoblasts. The wollastonite is fresh in appearance and free of any alterations. This appearance of wollastonite suggests a period of shallow contact metamorphism. This metamorphism is probably related to the injection of the Silurian to Devonian granitic bodies.

The quartz occurs as xenoblasts that are intergrown with the calcite, or occur as poikiloblasts within the calcite. The quartz shows extreme undulating extinction, an effect associated with a period of strain deformation.

II) Amphibolites:

The samples examined from the amphibolitic units in the study outcrop were CDS-13 and CDS-15. The only petrographic difference between these two samples involves the presence of diopside, CDS-15 does contain diopside while CDS-13 does not. Hornblende and bytownite are the chief constituents in these amphibolites. The hornblende subidioblasts vary in size from <.1mm to .7mm. It often displays a nematoblastic texture where this produced foliation is indicative of a later deformation. The hornblende is commonly intergrown with the bytownite xenoblasts, creating a sutured texture.

The bytownite ranges in size from .1mm to .5mm, and is characterized by Carlsbad-albite twinning. It is usually found containing small idioblasts of sericite. This sericitization of the bytownite suggests a period of low grade metamorphism in which the low grade mineral sericite, formed as an alteration product from the higher metamorphic grade mineral bytownite.

Biotite is associated with the hornblende in each sample. It occurs as poikiloblasts within the hornblende, and as intergrowths. This intergrown biotite-hornblende form the foliation in each sample (Figure 9).

Sphene is present as an accessory mineral. It cross cuts the other minerals, and is very fresh in appearance, with no evidence of alterations. This suggests that it was

Figure 9: Biotite-hornblende intergrowth present in the amphibolites.

Mag. 125X


a late forming mineral, probably related to a period of contact metamorphism.

The diopside found in CDS-15 is present as fractured xenoblasts. These xenoblasts do not follow the poor foliation developed by the hornblende and biotite. It is commonly intergrown with the bytownite, suggesting formation at the same time.

III) Paragneisses:

The paragneiss units found in the GRG include samples CDS-18, 20C, 24D, and 6B. The paragneisses can be divided into two groups, those containing chlorite, and those without chlorite. The two mineral assemblages characteristic of these groups are:

1) Quartz + oligoclase + biotite + kyanite + muscovite + chlorite

Quartz + oligoclase + biotite + kyanite + muscovite
 Quartz + oligoclase + biotite + kyanite + muscovite + chlorite

The samples contained in this assemblage are CDS-18 and 6B. The assemblage is characterized by a strong foliation, developed by the subparallel alinement of the biotite, chlorite, and kyanite blades within the mafic rich bands (Figure 10). The biotite and chlorite subidioblasts range in size from <.1mm to .6mm. They are commonly intergrown, and can occur as poikiloblasts within the quartz and oligo-

clase xenoblasts.

The quartzo-feldspathic bands contain xenoblasts of quartz and oligoclase, varying in size from <.1mm to .6mm. Minor biotite and kyanite are isolated within these bands. Fine grained muscovite, variety sericite, is present as an alteration within the oligoclase xenoblasts. The intensity of this sericitization of oligoclase is high, indicating an extensive period of low grade metamorphism.

Deformation in this assemblage is best defined by the biotite-chlorite foliation. This foliation is the only one visible and is probably related to a second deformation after a period of low grade metamorphism. The quartz xenoblasts show a wavy extinction and a poorly developed preferred orientation subparallel to the biotite-chlorite foliation. Evidence of the oxidation of the biotite idioblasts is seen from the presence of a mafic oxide rim, or intergrowth with the biotite idioblasts.

2) Quartz + oligoclast + biotite + kyanite + muscovite

The samples contained in this assemblage are CDS-20C and CDS-24D. These samples have a distinctive alternation of biotite-kyanite bands, with quartzo-feldspathic bands (Figure 11).

The biotite-kyanite bands are composed of idioblasts of biotite, kyanite ranging in size from .1mm to .6mm. The biotite and kyanite show a preferred orientation, yielding a lepidoblastic texture. Quartz and oligoclase xenoblasts

Figure 10: Strong foliation developed by subparallel alinement of biotite, chlorite, and kyanite blades within the mafic rich bands. Mag. 125X

Figure 11: Gneissic foliation defined by alternating biotite-kyanite bands, with quartzo-feldspathic bands.

Mag. 125X



are seen in these bands ranging in size from .1mm to .5mm.

The quartzo-feldspathic bands contain xenoblasts of quartz and oligoclase varying in size from .1mm to .6mm. Biotite and muscovite are present as small idioblastic poikiloblasts within the oligoclase.

Common to both bands is muscovite, variety sericite. It has formed due to a period of low grade metamorphism, in which the oligoclase has been altered to sericite. The seritized oligoclase xenoblasts help define the definite gneissic foliation across these samples.

Deformation is defined in this assemblage by the biotite-kyanite foliation. This deformation is the result of a second deformation which occurred after the high grade metamorphism, but before and during a period of contact metamorphism.

IV) Xenoliths:

Present within the marble units are irregularly shaped xenoliths ranging in size from 5cm to 1.5m. Samples of the two different types of xenoliths were studied, CDS-3A and CDS-2C. The two xenoliths types have the following assemblages respectively:

1) Forserite + calcite

Quartz + muscovite + orthoclase + tremolite
 Forsterite + calcite

This type of xenoltih (xenolith-A) is characterized

by the presence of large (.5mm to 3mm) xenoblasts of forsterite, set in a calcite matrix. The calcite is present as nodules, and as filling interstices between the large forsterite xenoblasts, and the smaller quartz xenoblasts.

This type of relationship between the forsterite and the calcite implies that the calcite formed after, or during the formation of the forsterite. The host rocks for the A-type xenoliths are diopside marbles that are 81 total volume percent calcite. The forsterite cannot be formed by reaction from a siliceous dolomitic limestone (Deer, Howie and Zussman 1980).

Xenolith-A must have formed from the metamorphism of a different rock type. This rock type was probably a siliceous dolomite. The forsterite and calcite found in xenolith-A, thus formed as follows:

dolomite + quartz = forsterite + calcite + CO₂

A piece of this high grade regionally metamorphosed siliceous dolomite was subsequently caught up in this host diopsidic limestone, forming a xenolith. The exact time of this xenolith emplacement is unknown, but it is probably related to the high grade regional metamorphism responsible for the formation of the forsterite. The development of serpentine within the forsterite xenoblasts suggests the xenolith formed before the period of low grade metamorphism responsible for the serpentine development. 2) Quartz + muscovite + orthoclase + tremolite

This second type of xenolith (xenolith-B) is charaeterized by a high proportion of fine grained quartz, muscovite and orthoclase xenoblasts. The orthoclase xenoblasts have undergone an intense period of seritization. Sericitemuscovite occurs as subidioblastic poikiloblasts within the orthoclase.

The quartz xenoblasts range in size from <.1mm to .4mm, and is commonly found as poikiloblasts within, or as intergrowths with the orthoclase and tremolite xenoblasts.

These B-type xenoliths are predominately restricted to the siliceous marble units of the GRG metasedimentary sequence. Xenolith-B has a petrographic composition that indicates a disequilibrium assemblage. The coexistence of orthoclase with microcline, and tremolite with muscovite are evidence of this disequilibrium assemblage. Xenolith-B was formed by the metamorphism and emplacement of a piece of previously formed rock common to the GRG metasedimentary sequence. The protolith for xenolith-B cannot be exactly determined from a petrographic study. All that can be stated is that it was not a calcareous type rock. If it was from a calcareous protolith, an A-type xenolith would have been formed. The exact time of emplacement of xenolith-B is unknown, but it probably occurred in association with the high grade regional metamorphism of the study area.

V) Granitic Bodies:

The granitic samples include CDS-23 and CDS-19. Sample CDS-23 is a biotite-muscovite granite, that is composed of large allotriomorphic crystals of orthoclase, quartz, and albite. Subhedral biotite and muscovite are present, ranging in size from <.1mm to .4mm. They are usually found, around the interlocking contacts of the anhedral quartz, albite and orthoclase (Figure 12) The albite and orthoclase occur as anhedral crystals ranging in size from .1mm to 2mm. Sericitization of the albite and orthoclase has occurred (Figure 13). Quartz occurs as anhedral crystals ranging in size from .1mm to 1.5mm. It is present as interlocking crystals with the albite and orthoclase, and as inclusions within the biotite and muscovite. The guartz and the albite commonly show a myrmekitic texture. Minor chlorite is present as intergrowths with the biotite crystals.

Sample CDS-19 is a muscovite tonalite. It consists of anhedral albite, quartz and orthoclase crystals, ranging in size from .1mm to 2mm. These crystals show a distinct interlocking texture. Development of a myrmekitic texture between the quartz and albite can be seen. Muscovite and chlorite are found intergrown, and as inclusions within the quartz, albite, and orthoclase. The quartz has a distinct undulating extinction, due to a period or periods of deformation. There are two sets of calcite-serpentine filled Figure 12: Subhedral biotite and muscovite found around the interlocking contacts of anhedral quartz, albite, and orthoclase. Mag. 125X

Figure 13: Intense sericitization of anhedral albite and orthoclase within the biotite-muscovite granite.

Mag. 125X



fractures that trend orthogonal to each other across the sample.

Xenoliths of heavily sericitized albite and orthoclase, with accessory chlorite are common in the granitic bodies. These xenoliths range in size from 1cm to 10cm. Quartz is present as anhedral crystals ranging in size from .1mm to .7mm in these xenoliths. It shows a very strong undulating extinction, and is free of any sericitization.

CHAPTER #3: PETROCHEMISTRY

I) Analytical Methods:

Whole rock analyses of samples from the marbles, paragneisses, amphibolites, xenoliths, and granitic bodies were obtained using X-ray fluorescence. The analyses were completed by X-ray Assay Laboratories Limited, Don Mills, Ontario, for Duval International Corporation. The major elements analyzed include Si, Al, Ca, Mg, Na, K, Fe, Mn, Ti, P, and Cr. The unnormalized whole rock analysis in weight percent oxides appear in Appendix B, and normalized values are presented in Table 4.

- II) Chemographic Plots:
- a) ACF Plot

The ACF plot is shown on Figure 14. The scheme for calculating the ACF ratios (after making the necessary corrections for accessories) are summarized in Winkler, 1979. The ACF plot shows that there are three distinct groups of rock compositions. The first group of three is clustered above the hornblende field, towards the alumina apex. The second cluster of three is within, and just to the left of the hornblende field. The last group is found near the calcium apex. This group is more varied in composition, but can be classified in broad terms as one very distinct

	TABLE	#4 W	HOLE ROC	K ANALY	SIS IN	WEIGH	T % OXIDE	<u>s (nor</u>	MALIZE	<u>:D</u>)		
	SiO ₂	^{Al} 2 ⁰ 3	Ca0	MgO	Na ₂ 0	К ₂ 0	Fe (Total)	Mn0	TiO ₂	P2 ⁰ 5	^{Cr} 2 ⁰ 3	LOI
MARBLES												
CDS 5	39.2	13.2	27.1	4.66	0.43	1.79	8.66	0.04	0.66	0.09		4.12
CDS 2B	0.41	0.11	55.38	0.69	0.08	0.03	0.11		0.01	0.17		43.01
CDS 16C	8.62	0.49	28.12	19.09	0.10	0.13	0.59	0.05	0.02	0.03		42.74
AMPHIBOLITES												
CDS 12C	41.3	16.6	15.5	11.2	0.45	0.52	10.1	0.13	0.82	0.16	0.04	2.82
CDS 13	47.6	17.8	9.49	6.55	3.09	1.30	11.2	0.16	0.79	0.20		1.72
CDS 15	47.7	17.6	8.10	7.14	3.17	1.45	11.0	0.14	0.79	0.28		2.61
PARAGNEISS '												
CDS 9	59.9	15.7	3.41	2.82	2.48	2.45	5.24	0.01	0.92	0.06	0.01	1.96
CDS 6B	56.9	17.2	7.43	2.92	2.46	2.43	6.70	0.05	0.78	0.12	0.01	3.58
CDS 24D	75.5	10.3	1.84	1.35	2.32	2.63	3.27	0.04	0.59	0.09	0.01	0.94
XENOLITHS												
CDS 4A	45.9	16.9	15.7	6.27	1.85	0.61	9.65	0.12	0.74	0.15		1.88
CDS 3A	42.0	16.9	20.5	5.28	0.27	0.13	11.8	0.21	0.70	0.16	0.01	1.96
CDS 2C	58.0	16.5	5.43	2.91	3.84	3.16	6.64	0.12	0.71	0.23		2.49
GRANITIC BODIES												
CDS 19	73.0	14.8	1.54	0.87	4.67	2.14	1.10	0.01	0.11	0.03	0.01	1.63
CDS 23	78.5	11.2	1.20	0.74	1.75	5.06	1.18	0.02	0.17	0.02	0.02	1.02

 $^{\rm W}_{\rm H}$

group.

The first group are the paragneisses. These paragneisses are rich in mafics, and alumina minerals. This is shown in their petrography where biotite and kyanite are present in substantial amounts. The potassium component, due to the abundance of biotite will tend to pull these compositions out of this projection towards the biotite field. This explains why these plots are not closer to the alumina apex than they are.

The paragneisses plot in an area of this ACF diagram, that corresponds to the greywacke-basic volcanic field established by Eskola, 1915. Since 1879, when the first recorded mapping of the study area was completed, the GRG has been regarded as a metasedimentary sequence. The field observations of the gneissic units; parallel bedding planes, and interbedding with marble units, indicates that the gneissic units are of sedimentary origin, possibly a greywacke, as suggested by the ACF Plot.

The second group of plots are the amphibolites. The plotting positions are acceptable for these amphibolites since they contain abundant hornblende, with only accessory biotite. The potassium component of the biotite has had only a small influence on the plotting positions. The plotting positions of the amphibolites do not give a clear indication of what the protolith was. It is therefore important to make use of the data obtained in the field work.







The amphibolite units are found as units interbedded with the marble, and paragneiss units. The contacts between the amphibolites and the surrounding units are very distinct and abrupt. These amphibolite units trend subparallel to the bedding of the surrounding marbles and paragneisses. Based entirely on these field observations, and the fact Wiebe 1972, also mapped a GRG metasedimentary sequence in northeastern Cape Breton Island as containing amphibolitic units that were derived from the metamorphism of basic dikes. The amphibolite units in this study outcrop are believed to have also resulted from the metamorphism of basic dikes, and not from the metamorphism of a pelitic protolith.

The third group of points on the ACF diagram represent marble mineral assemblages. As expected, the points are found predominantly towards the calcium apex. One point is found between the calcium and mafic apexes. This rock plots here due to the strong effect of the Mg component in the phlogopite pulling the composition towards the mafic apex. A chemographic plot more suitable for these marble assemblages is a SiO_2 -CaO-MgO plot (Turner, 1981). W.G. Melson, 1966 used this same chemographic plot for a calcsilicate, marble sequence found in Lewis and Clark County, Montana. This plot deals with the major, and most pertinent oxides found in marbles, and allows a much easier interpretation of possible protoliths.

b) SiO₂-CaO-MgO Plot

Figure 15 clearly shows the three different marble mineral assemblages found in the GRG. One of the assemblages (CDS-5) has a much larger SiO_2 component, thus forcing the plot towards the SiO_2 apex. This SiO_2 is contained in the quartz and vesuvianite that were observed in the petrographic analysis. Sample CDS-16C contains phlogopite which has forced the plot upwards towards the SiO_2 apex. Sample CDS-2B has a plotting position very close to the CaO apex. This is due to the fact that the sample contains 93 total volume percent calcite plus diopside.

Serpentine is present in samples CDS-2B and CDS-16C. From the plotting positions of the samples, the minerals that underwent hydration, resulting in the formation of serpentine, can be estimated. In CDS-2B, the diopside has been serpentinized, while forsterite has been serpentinized in sample CDS-16C.

Examination of the plotting positions reveals that the protolith for CDS-5 is a siliceous dolomitic limestone. The sample contains quartz, diopside, calcite, and wollastonite. Wollastonite is a high temperature, contact metamorphic mineral which forms by reaction of calcite + quartz. The quartz, calcite and diopside are common products of the regional metamorphism of siliceous dolomitic limestones (Winkler, 1979). The presence of calcite and quartz after a period of regional metamorphism will allow the formation

SiO2-CaO-MgO Plot



of wollastonite if a period of contact metamorphism follows.

Sample CDS-2B plots very close to the CaO apex. This plotting position suggests that the protolith must have been a very calcium rich rock, an almost pure limestone. The protolith does have a small, but important MgO and SiO₂ component, thus the protolith will be considered to be a siliceous-dolomitic limestone.

The plotting position of sample CDS-16C suggests that the protolith was a siliceous dolomite. The presence of forsterite indicates that quartz and dolomite must have been found in the protolith, and that the protolith has undergone a high grade metamorphism (Winkler, 1979). Forsterite will be formed as follows (Deer, Howie, and Zussman, 1980):

 $2CaMg(CO_3)_2 + SiO_2 = Mg_2SiO_4 + 2CaCO_3 + 2CO_2$. dolomite quartz forsterite calcite

III) Xenoliths

Plotting the chemical compositions of the xenoliths is difficult to do in order to be able to compare the results. From the XRF analysis, there are two types of xenoliths. The first, samples EDS-4A and CDS-3A, have a chemical composition that compares very closely to the chemical compositions of the amphibolites. This suggests that the protolith for xenolith-A may be the same as that for the amphibolite units, a basic volcanic rock.

The second xenolith type, sample CDS-2C, has a chemical composition that compares to the chemical composition of the paragneiss units. This xenolith type is distinctively different from the first type. It has a much higher SiO_2 , Na_2O , K_2O , proportion, and a distinctively lower CaO, MgO and Fe proportion. The chemical analysis suggests that the protolith for this xenolith type is the same as that for the paragneisses, a greywacke.

Establishing a protolith for each type of xenolith, based on the chemical compositions is unreliable and difficult to do. From the petrographic analysis, the protolith established for xenolith-A was a siliceous dolomite, while from chemical compositions, the protolith is a basic rock. Xenolith-A is 80 total volume percent forsterite and calcite. It is very uncommon to find a basic rock that has no pyroxenes and, this high a proportion of forsterite and calcite, thus the protolith for xenolith-A must be a siliceous dolomite.

From the petrographic and chemographic analysis of xenolith-B, the protolith was unable to be firmly established. The chemical composition compares strongly with the chemical composition of the paragneissic units, but the petrography does not closely compare. The petrography indicates a disequilibrium existing in this xenolith, thus any petrographic comparison cannot be reliably done. Based solely on the chemographic analysis of xenolith-B, its protolith would

seem to be the same as that for the paragneiss units, a greywacke.

IV) Granitic Bodies

A chemical analysis of samples CDS-23, and CDS-19 was carried out. These results have then been compared with analysis from other people on similar granitic rocks (D.T. Moore, V. Jones, and S.R. Nockolds).

Sample CDS-23 has a chemical composition that correlates to the analysis of similar biotite granites by Moore, Jones, and Nockolds. The SiO₂ value is higher than expected, but possible errors in laboratory work may account for this value. Other than this, the other major oxide values correlate well with those completed on similar biotite granites.

Sample CDS-19, a muscovite tonalite, has a composition that correlates with an average tonalite composition, established by S.R. Nockolds 1958. The important oxides to be considered are the CaO, Na₂O, and K₂O. The values of these reflect the composition of the feldspars in the sample. The high Na₂O+CaO values reflect an abundance of plagioclase feldspar, while a small K₂O value implies limited alkali feldspar being present. This is clearly shown in the petrographic descriptions. Albite is present as 40 total volume percent, while orthoclase is present as 8 total volume percent. It must be noted that muscovite is abundant in this sample, so it is probable that some of this K₂O will be found in muscovite, thus implying even a lower amount of orthoclase being present in the sample.

CHAPTER #4: METAMORPHISM

The estimated depositional age of the George River Group is 1400-1700 my. Since that time, the GRG in the study area has been metamorphosed. From the petrographic analysis, the study area has undergone three distinct periods of metamorphism. These three metamorphisms, in order of occurrence are:

- 1) High Grade Regional Metamorphism
- 2) Low Grade Regional Metamorphism
- 3) Contact Metamorphism.

Each period of metamorphism has created appropriate mineral assemblages, corresponding to the grade of each metamorphism. The metamorphic mineral assemblages observed in the study area have been tabulated in Table 5.

I) High Grade Regional Metamorphism

a) Grade:

The metamorphic mineral assemblages created by the regional metamorphism of the established protoliths, are listed in Table 5. Forsterite, diopside, and kyanite bearing assemblages characterize the high grade metamorphic minerals. These minerals indicate that the regional metamorphism is of kyanite grade. This high grade regional metamorphism is believed to be related to the emplacement of

TABLE 5: METAMORPHIC MINERAL ASSEMBLAGES

PROTOLITH	REGIONAL METAMORPHIC MINERAL ASSEMBLAGE	LOW GRADE METAMORPHIC MINERAL ASSEMBLAGE	CONTACT METAMORPHIC MINERAL ASSEMBLAGE		
SILICEOUS DOLOMITIC LIMESTONE	calcite + diopside <u>+</u> quartz	serpentine	vesuvianite <u>+</u> wollastonite + sphene		
SILICEOUS DOLOMITE	calcite + forsterite	serpentine	phlogopite		
GREYWACKE	kyanite + oligoclase + biotite + quartz <u>+</u> microcline	sericite + chlorite	sphene		
BASIC VOLCANIC SILLS	hornblende + bytownite + biotite + quartz <u>+</u> diopside	sericite + chlorite	sphene		
GREYWACKE (Xenolith-B)	muscovite + quartz + orthoclase + microcline	chlorite + sericite	vesuvianite + sphene		
GRADE	Kyanite	Chlorite	Wollastonite		

the older dioritic plutons associated with the Grenville orogeny, 900-1000 my.(Wiebe, 1972).

b) P-T Estimates:

From the mineral assemblages listed for the regional metamorphism, the study outcrop at that time belonged to the Almandine-Amphibolite Facies of regional metamorphism. Bv no means all amphibolites of this facies must contain almandine (Turner and Verhoogen, 1960). This is the case for the study outcrop at the time of regional metamorphism. Metamorphism in the almandine-amphibolite facies covers a temperature range of 550° to 750° C and pressures between 4 and 8 kbars (Turner and Verhoogen, 1960). The presence of kyanite however suggests that for a temperature range of 550° to 750°C, a pressure exceeding 8 kbars is necessary. A pressure of 10 to 13 kbars would allow for the formation of kyanite within the temperature range established by Turner and Verhoogen, 1960. The estimated pressure-temperature conditions of this regional metamorphism are:

a) temperature = 550° to 750° C

b) pressure = 10-13 kbars

c) Metamorphic Mineral Reactions Present:

The most interesting reactions associated with the high grade regional metamorphism are those that occurred within the calcareous units, and those responsible for the formation of kyanite and biotite in the greywacke units.

In the siliceous dolomitic limestone units, the

characteristic metamorphic mineral assemblage is calcite + diopside <u>+</u> quartz. Diopside forms, following tremolite, early in the metamorphism of siliceous dolomitic limestones. The sequence of reactions (Deer, Howie and Zussman, 1980) that will form this calcite + diopside <u>+</u> quartz assemblage is:

$$5CaMg(CO_3)_2 + 8SiO_2 + H_2O = Ca_2Mg_5Si_8O_{22}(OH)_2 + 3CaCO_3 + 7CO_2 (1)$$

dolomite + quartz = tremolite + calcite

With increased metamorphism, the tremolite is unstable and if SiO_2 is still available diopside will be formed as follows:

$$Ca_{2}Mg_{5}Si_{8}O_{22}(OH)_{2} + 3CaCO_{3} + 2SiO_{2} = 5CaMgSi_{2}O_{6} + 3CO_{2} + H_{2}O \quad (2)$$

tremolite calcite quartz diopside

In reaction (2), it must be assumed that the calcite is in excess and is not all used up in the formation of the diopside. If this is the case, the combination of reactions (1) and (2) will yield a calcite + diopside assemblage. If the quartz is also in excess and is not completely used up in the reactions, the assemblage calcite + diopside + quartz will be formed. The amount of quartz in the protolith will determine whether or not quartz will be present in the rock after the regional metamorphism.

The characteristic assemblage present in the siliceous dolomites is calcite + forsterite. The formation of forsterite and calcite is due to the reaction (Deer, Howie, and Zussman, 1980):

 $2CaMg(CO_3)_2 + SiO_2 = Mg_2SiO_4 + 2CaCO_3 + 2CO_2$ (3) dolomite quartz forsterite calcite

The greywacke regional metamorphic mineral assemblage is characterized by the coexistence of biotite + kyanite. The biotite and kyanite defines a distinct gneissic banding and metamorphic foliation across the observed samples. This foliation, defined by the biotite and kyanite suggests formation of both by one high grade metamorphic reaction (Winkler, 1979):

staurolite + muscovite + quartz = kyanite + biotite + H_2O (4)

A high temperature and pressure regional metamorphism, (the type established for this study area), will lead to the breakdown of the earlier formed staurolite and subsequent formation of kyanite. If the temperature increases, sillimanite may form instead of the kyanite.

II) Low Grade Regional Metamorphism

a) Grade:

After a period of high grade regional metamorphism, the study area underwent a period of low grade metamorphism. Evidence is the development of low grade metamorphic minerals such as chlorite, serpentine, and sericite. The sericite

and chlorite are characteristic of the greywacke units, while serpentine is characteristic of the siliceous dolomites, and siliceous dolomitic limestones. Textural relations indicate that these low grade minerals formed as alteration products from minerals of high metamorphic grade. The development of these low grade minerals indicates that the low grade metamorphism was of chlorite grade.

b) P-T Estimates:

Estimates of pressures and temperatures of low grade regional metamorphisms are difficult to obtain. A possible range, determined by experimental data on the stability of these greenschist minerals is 300° to 500° C and P_{H_20} = 3 to 8 kbars (Turner and Verhoogen, 1960). Johannes, 1968 states that the highest temperature at which serpentine remains stable is 500° C. This temperature will mark the high temperature boundary for this period of low grade regional metamorphism. The temperature and pressure estimates for the low grade regional metamorphism are:

a) temperature = 300° to 500° C

b) pressure = 3 to 8 kbars

c) Metamorphic Mineral Reactions Present:

The formation of sericite, chlorite and serpentine are of importance. Textural evidence indicates that these minerals have been derived by alteration of high grade metamorphic minerals. Hydrolysis of these high grade minerals has created the low grade minerals. Hydrogen ions are added to the high grade minerals, resulting in a mole equivalent loss of metal cations from the high grade minerals. The result is the formation of a lower grade metamorphic mineral.

In the samples studied, sericite has been derived from both plagioclase and alkali feldspars. Sericitization in an aqueous solution is an example of hydrolysis. The reactions responsible for sericitization of the plagioclase and alkali feldspars, from Hemley and Jones 1964, are:

$$1.5 \text{KAlSi}_{3} \circ_{8} + \text{H}^{+} = 0.5 \text{KAl}_{3} \circ_{10} (\text{OH})_{2} + \text{K}^{+} + 3 \circ_{2}$$
(5)
alkali feldspar sericite quartz

$$0.75Na_2CaAl_4Si_8O_{24} + 2H^+ + K^+ = KAl_3Si_3O_{10}(OH)_2 + 1.5Na^+ + 0.75Ca^{++}$$

+3SiO₂ (6)
plagioclase sericite quartz

The K^+ needed in the hydrolysis of the plagioclase may possibly be derived from the breakdown of the alkali feldspars (Hemley and Jones, 1964).

The chlorite in the greywacke units has been derived from the hydrolysis of biotite. Evidence is the symplectite intergrowth texture of the biotite and chlorite. Chloritization of biotite is another example of exchange of hydrogen ions for other cations (Hemley and Meyer, 1967):

$$2K(Mg,Fe)_{3}AlSi_{3}O_{10}(OH)_{2} + 4H^{+} = Al(Mg,Fe)_{5}AlSi_{3}O_{10}(OH)_{8} + Chlorite$$

$$(Mg,Fe)^{++} 2K^{-} + 3SiO_{2}$$

$$(Mg,Fe)^{++} 2K^{-} + 3SiO_{2}$$

$$(Mg,Fe)^{++} 2K^{-} + 3SiO_{2}$$

Chlorite is an important phase of alteration in zones where there have been additions of magnesium and/or iron. In the greywacke units, this magnesium and iron are contained within the biotite. This explains the formation of chlorite from the biotite in these greywacke units.

Serpentine is present within the dolomitic units of the study area. It has been derived from the hydrolysis of forsterite and diopside. The reaction for the formation of serpentine from the hydrolysis of forsterite is as follows (Deer, Howie, and Zussman, 1980):

$$3Mg_2SiO_4 + 4H_2O + SiO_2 = 2Mg_3Si_2O_5(OH)_4$$
(8)
forsterite serpentine

The hydrolysis of diopside can also produce serpentine as an alteration product. A possible reaction is as follows:

$$3Ca(Mg,Fe)(SiO_3)_2 + 7H_2O + 6H^+ = Mg_3Si_2O_5(OH)_4 + 4H_4SiO_4$$

diopside serpentine (9)
+ $3Ca^{++}$

Notice that silica, in a dissolved state is also produced. This is the only way the magnesium can be concentrated into the serpentine. SiO₂ must be released from diopside in order to produce serpentine.

III) Contact Metamorphism

a) Grade:

The contact metamorphism of the entire sequence is

evident, due to the presence of various unaltered contact metamorphic minerals. The siliceous dolomites are characterized by the presence of phlogopite, and the siliceous dolomitic limestones are characterized by wollastonite, vesuvianite and sphene. In the greywacke units, sphene is the only contact metamorphic mineral present. The contact metamorphism is the result of the intrusion of the granite and tonalite bodies. These intrusives definitely post date both the high and low grade regional metamorphism, because they contain xenoliths of heavily sericitized albite and orthoclase. The sericitized feldspars are the result of the low grade regional metamorphism of the GRG. The contact metamorphism is of wollastonite grade.

b) P-T Estimates:

The formation of wollastonite takes place in the higher temperature ranges of shallow contact metamorphism. It forms as follows (Greenwood, 1967):

$$CaCO_3 + SiO_2 = CaSiO_3 + CO_2$$
 (10)
calcite quartz wollastonite

In order for this reaction to form wollastonite, the pressure of the CO₂-rich fluid must be low, and the temperature must be between 550° C and 800° C. These conditions are shown graphically in Figure 16 (Greenwood, 1967). A third variable or condition important in the formation of wollastonite is the X_{CO₂} of the fluid present during

metamorphism. Wollastonite will only be formed if the X_{CO_2} of the fluid is rather large, .25 to 1.0 (Greenwood, 1967). These three conditions, temperature, pressure, and X_{CO_2} of the fluid, define the area of wollastonite formation on Figure 16 (Greenwood, 1967).

The temperature and pressure needed for reaction (10) to proceed and form wollastonite will be used to estimate the temperature and pressure of the contact metamorphism. The estimated conditions are:

a) temperature = $550 \text{ to } 800^{\circ}\text{C}$

b) pressure = 500 to 3000 bars

c) Metamorphic Mineral Reactions Present:

The contact metamorphism has resulted in the formation of various contact minerals, phlogopite, wollastonite, vesuvianite, and sphene.

Reaction (10) shows the reaction necessary for the formation of wollastonite. It should be noted that not all the siliceous dolomitic limestones contain wollastonite. If there is a substantial SiO_2 proportion in the mineral assemblages within the siliceous dolomitic limestones, wollastonite will form. If the assemblage is lacking SiO_2 , no wollastonite will be formed.

Sphene is commonly found as a contact metamorphic mineral in calcareous rocks. In the siliceous dolomitic limestones, the reaction (derived from Ramberg, 1953) responsible for the formation of sphene is: Figure 16: The area of wollastonite formation. The conditions, temperature, pressure, and X_{CO_2} of the fluid define the area. The X_{CO_2} of the fluid is large, .25 to 1.0 (Greenwood, 1967). The reaction for the formation of wollastonite is as follows:

 $CaCO_3 + SiO_2 = CaSiO_3 + CO_2$ calcite quartz wollastonite



Wollastonite Formation

$$SiO_2 + TiO_2 + CaCO_3 = CaTiSiO_5 + CO_2$$
 (11)
quartz rutile calcite sphene

Rutile is a widely distributed accessory mineral in metamorphic rocks, thus the formation of sphene from accessory rutile inreaction with quartz and calcite is very possible. Sphene is also very common in the greywackes as a contact metamorphic mineral. It is commonly associated with rocks that are rich in ferromagnesium minerals, as is the case for these greywacke units. It has formed by a reaction similar to that of reaction (11), but will possibly involve a different source of Ca than that found in the calcite. This Ca may be from the hornblende or diopside present.

Phlogopite is a common contact metamorphic mineral found in the siliceous dolomite units. A possible reaction for its formation is difficult to foresee, due to the fact that calcite, forsterite, and serpentine are the only minerals that are present that could react to form phlogopite. A source of potassium is needed for the formation of phlogopite. None of the minerals present in the siliceous dolomites contain potassium thus establishing a probable formation reaction for phlogopite is difficult to do.

Vesuvianite is a common constituent in calcium-rich rocks of contact metamorphism where it commonly occurs with wollastonite (Deer, Howie, and Zussman, 1980). The vesu-

vianite may have formed from a reaction involving calcite, dolomite, quartz, and an aluminum-bearing mineral (Braitsch, and Chatterjee, 1963). No aluminum-bearing minerals are present in the siliceous dolomitic limestones as seen from the petrographic study so Al³⁺ will be used instead of an aluminum-bearing mineral. The reaction is as follows (derived from Braitsch, and Chatterjee, 1963):

$$CaCO_{3} + CaMg(CO_{3})_{2} 2SiO_{2} + 2Al^{3+} + H_{2}O = Ca_{2}Al_{2}(OH)Si_{2}O_{7} + calcite dolomite quartz vesuvianite (12) Mg^{2+} 3CO_{2} + H^{+}$$

This reaction appears to be the only possible reaction that can apply to the siliceous dolomitic limestones of the GRG. There is no basis on which to name the aluminumbearing mineral needed in order for vesuvianite to form. It is possible that a clay mineral may be the source of the aluminum for the formation of vesuvianite.

IV) Amphibolites:

From the petrochemistry, and field observations, the amphibolites were found to have formed from the metamorphism of basic volcanic sills or dikes. The development of various high grade metamorphic minerals indicates that the basic sills were emplaced before or during the regional metamorphism of the study area. The high grade regional, low grade regional, and contact metamorphism mineral assemblages are listed in Table 5. The high grade regional
assemblage is characterized by hornblende + biotite + quartz + bytownite + diopside.

Hornblende is characteristic of regionally metamorphosed rocks, and is stable under a wide range of temperature and pressure conditions. The hornblende in these metamorphosed basic sills may have formed by the high grade metamorphism of enstatite which may be found in volcanic rocks. The reaction (Ramberg, 1953) is as follows:

 $2CaAl_{2}Si_{2}O_{8} + 3(Mg,Fe)SiO_{3}H_{2}O = Ca_{2}(Mg,Fe)_{3}Al_{4}Si_{6}O_{22}(OH)_{2}$ anorthite enstatite hornblende (13) + SiO_{2}

The diopside that may be present in these amphibolites has in all probability been formed by the metamorphism of tremolite. Tremolite will form early in the high grade regional metamorphism, and with increased grade it will form diopside (reaction (2)).

The low grade regional metamorphic mineral assemblage is characterized by sericite and chlorite. Sericite has formed by the hydrolysis of bytownite, while the chlorite has formed by the hydrolysis of biotite (reactions (6) and (7)). It is also possible that the chlorite may have formed by the hydrolysis of hornblende in a reaction similar to that of reaction (7).

Sphene is the characteristic contact metamorphic mineral present. Its mode of formation has been previously

explained.

V) Xenoliths:

Two distinct types of xenoliths are present in the study area, xenolith-A and xenolith-B. Both have witnessed the three periods of metamorphism that have effected the study area. The emplacement of these xenoliths probably occurred contemporaneously with the high grade regional metamorphism. This is proven by the presence of high grade, low grade, and contact metamorphic minerals within the xenoliths.

As previously mentioned, xenolith-A has formed by the emplacement and metamorphism of a piece of siliceous dolomite. The high grade regional metamorphism resulted in the formation of forsterite (reaction (3)), with the serpentine being formed by the subsequent hydrolysis or low grade regional metamorphism of the forsterite (reaction (8)). Sphene is present as a distinct contact metamorphic mineral, having formed by reaction (11). The metamorphic mineral assemblages resulting from these three periods of metamorphism are listed in Table 5, under the siliceous dolomite protoliths.

Due to the distinct disequilibrium assemblages present in xenolith-B, the metamorphic mineral assemblages for each period of metamorphism do no appear in Table 5. Since a disequilibrium is present in this sample, deter-

minations of reactions responsible for the various metamorphic minerals cannot be completed.

VI) Contribution Towards an Orogenic Model:

The aim of this metamorphic study was to unravel the metamorphic history of a portion of the George River Group. This has been done through careful mineralogical and textural studies supplemented by outcrop relations. The following sequence of the metamorphic history, can be deduced from the preceding study of the GRG.

A) deposition of GRG (1400-1700 my.)

i) intrusion of basic volcanic sills and dikesB) high grade regional metamorphism

i) kyanite grade

ii) emplacement and metamorphism of xenoliths

C) low grade regional metamorphism

i) chlorite grade

D) folding and granitic injections

E) contact metamorphism

i) wollastonite grade

The period of deposition for the GRG, established by Wiebe 1972 is 1400-1700 my. The appearance of amphibolitic units trending bedding parallel to subparallel suggests the injection of basic volcanic sills during this deposition. The development of high grade regional metamorphic minerals occur in these deposited units. This regional metamorphism is of kyanite grade, $T = 550^{\circ}$ to $750^{\circ}C$, P = 10-13 kbars, and is believed to be related to the emplacement of Grenvillian aged (900-1000 my.) diorite plutons, particularly the emplacement of the Ingonish River Pluton (Wiebe 1972). This pluton is found in the immediate vicinity of the GRG study area. A period of folding is believed to have been associated with the Grenville orogeny, but no evidence is present in the study area.

A period of low grade metamorphism followed and created various low grade minerals derived from the hydrolysis of the higher metamorphic grade minerals. This metamorphism continued until the Acadian orogeny when the entire sequence was folded and metamorphosed by the injection of Silurian aged (Wiebe 1972) granitic bodies. The evidence of this folding event is the increased development of a bedding parallel gneissic foliation in the greywacke units and a schistosity in the amphibolite units. The granite body injection created a contact metamorphism of wollastonite grade. The estimated temperature and pressure of the contact metamorphism are 550° to 800°C and 500-3000 bars. There is no evidence for any other periods of metamorphism effecting the GRG since this last folding and contact metamorphism event.

This proposed sequence of metamorphic events does, in principle, follow the summary of events in northeastern Cape Breton Island established by Wiebe 1972. No evidence

of an early major folding event is seen in the study area, but has been noted as an important tectonic event by Wiebe. Grades of metamorphism have been established and associated with the tectonic events proposed by Wiebe 1972.

CHAPTER 5: CONCLUSION

The George River Group, Cape Breton Island is composed of interbedded marble and paragneiss units. Amphibolites, derived from the metamorphism of basic volcanic dikes are found discordant to the bedding. Felsic dikes and larger granitic bodies are commonly found intruding the GRG sequence.

A petrographic study of the GRG indicated that it had undergone three distinct periods of metamorphism. The first was a period of kyanite grade regional metamorphism. This regional metamorphism is believed to be associated with the Grenville orogeny (900-1000 my.) in which older dioritic plutons were injected into Northeastern Cape Breton Island. The high grade metamorphic minerals formed by this metamorphism are listed in Table 5.

A chlorite grade regional metamorphism followed, creating such low grade minerals as chlorite, sericite and serpentine. These minerals were formed by the hydrolysis of biotite, feldspar, forsterite and diopside respectively.

A wollastonite grade contact metamorphism followed the low grade regional metamorphism. This contact metamorphism resulted from the injection of smaller granitic bodies related to the Acadian orogeny (410 my.). Complex

metamorphic mineral assemblages were developed in the calcareous units of the GRG. Wollastonite, vesuvianite, phlogopite and sphene characterize these assemblages in the calcareous units.

The paragneiss and amphibolite units contain a strong foliation. This was partially developed in the high grade regional metamorphism, and further developed by folding associted with the contact metamorphism.

From the petrographic and chemographic analysis completed, the metamorphic grade of the George River Group is of kyanite grade. Previous work in establishment of a metamorphic grade has been limited, but a sillimanite grade is usually used when describing the grade of the GRG. The petrographic analysis completed in this study clearly indicates that kyanite, not sillimanite is the index mineral that should be used when establishing the metamorphic grade of the George River Group.

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APPENDIX A

PETROGRAPHIC DESCRIPTIONS

AND

SKETCHES

Figure 17: Sample location map.



SAMPLE LOCATION MAP

SAMPLE: CDS-2B

CLASSIFICATION: Serpentinized Marble with Diopside Xenoblasts MODAL ABUNDANCES: Calcite 81% Diopside 12% Serpentine 5%

2%

Opaques

TEXTURES: The thin section contains small rounded xenoblasts of diopside, set in a xenoblastic coarse grained calcite matrix. The diopside ranges in size from <.1mm to .3mm in diameter, with the calcite ranging in size from .1mm to .4mm. Diopside xenoblasts are relatively evenly distributed across the sample, with isolated areas having a higher concentration than average. The distinctive sutured texture, and occurrence of bent and deformed cleavage traces within the calcite xenoblasts suggest a period of calcite recrystallization. Poikiloblasts of calcite within the calcite xenoblasts are also suggestive of a recrystallization period.

Serpentine is present as the alteration product of the diopside xenoblasts. It is seen either as partially or completely altering the diopside. The waters responsible for the serpentinization have left the entire section with a distinctive brown whispy coloured appearance. Fractures within the sample allowed this fluid to flow and percolate through the sample creating the alterations.



SAMPLE: CDS-11

CLASSIFICATION: Serpentinized Marble

MODAL	ABUNDANCES :	Calcite	65%
		Serpentine	30%
		Phlogopite	5%
		Opaques	<1%

TEXTURES: This sample is characterized by isolated and aggregated xenoblasts of serpentine set in a calcite matrix with minor phlogopite and opaques. The antigorite xenoblasts range from .1mm to 2mm in size. The antigorite has completely replaced its parent mineral, which was probably forsterite. Within the antigorite xenoblasts, calcite poikiloblasts are found. These poikiloblasts average .1mm in size, and are usually found as centres in the serpentine xenoblasts.

Phlogopite occurs as tabular, to fibrous idioblasts which are found as symplectite intergrowths with the calcite. The phlogopite is fresh, and free of any alterations.

Calcite dominates the sample. It is xenoblastic and creates a sutured texture, formed during a period of recrystallization. Poikiloblasts of calcite within the larger calcite xenoblasts commonly occur, also suggesting recrystallization. Evidence of serpentine along cleavage traces in calcite is present.

The opaques are essentially pyrite, with minor chalcopyrite. These opaques often contain xenoblastic calcite and serpentine poikiloblasts. A minor foliation, the result of concentrated serpentine in bands or small veinlets cross the section, parallel to subparallel to the bedding.



SAMPLE: CDS-14A

CLASSIFICATION: Serpentinized Marble

MODAL	ABUNDANCES :	Calcite	64%
		Serpentine	25%
		Phlogopite	5%
		Forsterite	4%
		Quartz	2%
		Opaques	<1%

TEXTURES: The sample is characterized by serpentine, set in a matrix of calcite with accessory phlogopite, quartz, and opaque minerals. The antigorite occurs as xenoblastic pseudomorphs of forsterite, with some forsterite visible through the antigorite. The antigorite xenoblasts range from .2mm to .8mm in size, with a relatively even distribution across the sample.

The calcite occurs as xenoblasts exhibiting a sutured texture. Calcite commonly occurs as poikiloblasts within the serpentine pseudomorphs and with the larger calcite xenoblasts. The calcite rhombohedral cleavage traces are at times well developed, but more commonly occur broken and bent. Edges of these xenoblasts have a gold-brown rim, the result of the action of serpentine rich fluids.

Phlogopite and quartz commonly occur as small <.1mm to .3mm poikiloblasts with calcite xenoblasts. The phlogopite is tabular in form and often is seen as exhibiting a symplectite texture with the calcite. Opaque minerals are dominantly pyrite and possibly graphite. They commonly occur as opaque rims around the forsterite xenoblasts.

A foliation defined by discontinuous bands of serpentine crossing the sample parallel to subparallel to the bedding is clearly visible in the hand sample.



Mag 100X

SAMPLE: CDS-16C

CLASSI	FICATION:	Phlogopite Mar	rble
MODAL	ABUNDANCES	calcite	64%
		Phlogopite	20%
		Serpentine	10%
		Opaques	5%
		Quartz	<1%

TEXTURES: This sample is characterized by the presence of two varieties of serpentine, and abundant phlogopite, set in a calcite matrix. Both varieties appear to be derived from forsterite, except each has its own distinct form. One variety occurs as rounded xenoblasts, while the other variety occurs as tabular idioblasts. Calcite and opaque minerals occur as poikiloblasts, and may be intergrown with the serpentine pseudomorphs.

The calcite occurs as .1mm to .7mm xenoblasts which create a distinctive sutured texture. It is commonly intergrown with the phlogopite and serpentine xenoblasts. As a general rule, the cleavage traces are not well developed. This suggests a period of calcite recrystallization. The calcite xenoblasts often contain quartz and phlogopite poikiloblasts which range from <.1mm to .4mm in size.

The phlogopite idioblasts range in size from .1mm to .6mm. They are commonly tabular, and found as poikiloblasts or intergrowths with the calcite. The phlogopite is fresh in appearance, and has not been altered to any great

extent.

The opaque minerals consist of pyrite and chalcopyrite. They occur as intergrowths with serpentine, and as linear poikiloblasts along cleavage and twins within the calcite xenoblasts.

Orientated with no preferred direction are a series of fractures. These fractures cut all minerals, and often contain concentrated amounts of opaque minerals and serpentine. Other than these fractures, the sample is massive in character, with no foliation present at all.



SAMPLE: CDS-5

CLASSIFICATION: Siliceous Marble

MODAL	ABUNDANCES :	Calcite	70%
		Quartz	9%
		Vesuvianite	8%
-		Diopside	7%
	Wollastonite	3%	
		Opaques	2%
		Sphene	1%

TEXTURES: The thin section is characterized by the appearance of diopside, wollastonite, and vesuvianite, set in a siliceous calcite matrix. The calcite xenoblasts range in size from .2mm to 2.5mm. Mutual grain boundaries are irregular in form, creating a sutured texture. This sutured texture, and calcite poikiloblasts within the calcite xenoblasts suggest a period of calcite recrystallization. The xenoblasts show a symplectite texture with the quartz, diopside and vesuvianite xenoblasts. Preservation of crystal laminae is good, allowing rhombohedral cleavage to be seen easily.

The diopside occurs as xenoblasts ranging in size from .1mm to 2mm. They are severely fractured and are commonly intergrown with quartz and calcite.

The vesuvianite is present as subidioblasts that range in size from .1mm to 2mm. It is commonly fractured and intergrown with calcite xenoblasts. The vesuvianite subidioblasts are the largest crystals present. They show cross cutting relationships with the other minerals, suggesting they formed at a later time, possibly during the contact metamorphism event.

The wollastonite present, occurs as fibrous to tabular idioblasts ranging in size from .3mm to .5mm. It is commonly intergrown with the quartz, and is found cutting across the crystal boundaries of the other minerals present.

The quartz xenoblasts range in size from <.1mm to .2mm. They occur as intergrowths with the calcite and wollastonite. The xenoblasts show an undulating extinction indicating a deformation event or events.

Accessory opaque minerals (chalcopyrite), and sphene are present as small xenoblasts within the thin section.



SAMPLE: CDS-13

CLASSIFICATION: Hornblendite			
MODAL ABUNDANCES:	Hornblende	60%	
	Bytownite	20%	
	Biotite	7%	
	Muscovite	5%	
	Quartz	3%	
	Sphene	2%	
	Opaques	2%	
	Zircon	<1%	

TEXTURES: Hornblende and bytownite are the major constituents of this sample. The hornblende occurs as subidioblasts ranging in size from <.1mm to .3mm. A distinct nematoblastic texture, developed from the subparallel alinement of hornblende, gives this sample a poorly developed fissility. Poikiloblasts of bytownite and biotite are found within these hornblende subidioblasts. The essentially tabular hornblende creates a mosaic texture with the surrounding bytownite.

The bytownite occurs as xenoblasts ranging from .1mm to .4mm in size. Most of these xenoblasts are characterized by the presence of albite, and or Carlsbad twins. The bytownite is commonly intergrown with the hornblende, creating a symplectite texture. Development of sericite around the edges of the bytownite xenoblasts is common. This sericite occurs as small, <.1mm idioblasts. Biotite occurs as small subidioblastic poikiloblasts within hornblende, and as intergrowths with the hornblende. The biotite commonly contains accessory zircons surrounded by pleochroic halos. The biotite idioblasts show a slight lepidoblastic texture which parallels the foliation developed by the subparallel alinement of the hornblende idioblasts.

Sphene, quartz, and opaque minerals occur as accessories. The sphene occurs as rhombohedral idioblasts that range in size from .1mm to .2mm. The opaque minerals are essentially magnetite and pyrite. These occur as xenoblasts that are elongate in the direction of the foliation.

Zones of concentrated sericite muscovite and fractures, are seen orthogonal to the foliation. These zones are .5mm wide and occur as bands across the foliation.



SAMPLE: CDS-15

CLASSIFICATION: Amphibolite

MODAL	ABUNDANCES :	Hornblende	3 <i>5</i> %
		Biotite	15%
		Muscovite	15%
		Diopside	10%
		Bytownite	10%
		Opaques	5%
		Quartz	5%
		Sphene	5%

TEXTURES: The sample is characterized by the high degree of sericitic alteration of the bytownite. The bytownite occurs as xenoblasts ranging in size from .1mm to .6mm. The sericite is present as tabular subidioblasts that commonly occur around the edges of the bytownite xenoblasts. Bytownite is intergrown with the hornblende, biotite and diopside throughout the slide.

The hornblende occurs as subidioblasts ranging in size from .1mm to .6mm. It is commonly fractured and intergrown with biotite. The hornblende and biotite produce a decussate texture that defines a poorly developed fissility in the sample. The hornblende commonly contains poikiloblasts of bytownite and sericite.

Present as xenoblastic, fractured crystals, is diopside. It ranges in size from <.1mm to .4mm. A symplectite texture involving the diopside and bytownite is seen, with the bytownite filling in fractures, and surrounding the diopside.

Sphene, quartz, and opaque minerals occur as accessories. The sphene is present as .1mm idioblastic rhoms, and as aggregates that cross cut all other minerals in the sample. Quartz occurs as xenoblasts ranging in size from .1mm to .4mm. It occurs as poikiloblasts in the opaques, and as interlocking crystals with the hornblende and biotite.



86

Mag 10CX

SAMPLE: CDS-18

CLASSIFICATION: Biotite-Chlorite Paragneiss

MODAL ABUNDANCES :

Quartz	30%
Muscovite	25%
Biotite	20%
Chlorite	15%
Kyanite	5%
Oligoclase	5%
Zircon	1%
Opaques	1%

TEXTURES: The sample contains idioblasts of chlorite and biotite, set in a quartz, and sericitized oligoclase matrix. The chlorite occurs as idioblasts ranging in size from

<.1mm to .3mm. It is intergrown with the biotite, and is commonly found a poikiloblasts with sericitized oligoclase. The chlorite and biotite show a lepidoblastic texture which defines the strong fissility in the sample.

The biotite occurs as idioblasts ranging in size from .1mm to .7mm. It is present as intergrowths with chlorite, and as poikiloblasts within oligoclase.

The quartz occurs as strained xenoblasts that are commonly found as poikiloblasts within the sericitized oligoclase. The quartz ranges in size from <.1mm to .4mm.

Kyanite is present as elongated subidioblasts that are orientated parallel to the foliation developed by the chlorite and biotite idioblasts. The kyanite varies in size from .1mm to .7mm, and is usually fractured, giving it a "ratty" appearance.

Oligoclase occurs as xenoblasts ranging in size from .1mm to .4mm. All oligoclase present has been altered to sericite, with many oligoclase xenoblasts being completely replaced. The oligoclase is commonly intergrown with the biotite, chlorite, and kyanite, and can be found as small poikiloblasts in quartz.

The accessory minerals zircon, and opaques are present. The zircon is present as poikiloblasts within biotite idioblasts, while the opaques commonly occur as intergrowths with the biotite idioblasts.

The hand sample shows a distinct alternation of darker chlorite-biotite bands with the more quartzofeldspathic, quartz-oligoclase bands. This defines the gneissic foliation present.


SAMPLE: CDS-20C

CLASSIFICATION: Quartz-Biotite Paragneiss

MODAL	ABUNDANCES :	Quartz	30%
		Biotite	25%
		Muscovite	20%
		Oligoclase	10%
		Kyanite	7%
		Calcite	3%
		Zircon	1%
		Opaques	1%

TEXTURES: Distinctive banding of biotite, kyanite, and muscovite with quartz and sericitized oligoclase gives the sample a gneissic foliation. In the mafic rich bands, the biotite occurs as idioblasts ranging in size from .1mm to .4mm. Biotite and kyanite are commonly intergrown, and show a lepidoblastic texture. Biotite idioblasts commonly occur as poikiloblasts within quartz and the sericitized oligoclast xenoblasts.

The kyanite occurs as subidioblasts, ranging in size from .2mm to .7mm. It shows a lepidoblastic texture, and a symplectite texture with biotite, muscovite, and oligoclase. The kyanite is commonly fractured, giving it a "ratty" appearance.

Muscovite occurs as idioblasts ranging in size from <.1mm to .3mm. It is present as intergrowths with oligoclase xenoblasts and kyanite subidioblasts. The quartzo-feldspathic bands are composed of xenoblasts of quartz, and sericitized oligoclase. These bands contain minor biotite, which is present as poikiloblasts within quartz xenoblasts. Sericite is present in all oligoclase xenoblasts, giving them a discoloured dark brown colour. The oligoclase xenoblasts range in size from .1mm to .6mm.

The accessory minerals, calcite, zircon and opaque minerals are present in both types of bands. Calcite occurs as small xenoblasts intergrown with kyanite and biotite. Zircons are present as small poikiloblasts within the biotite. A pleochroic halo is found around each zircon poikiloblast. The opaques are present as xenoblasts ranging in size from .1mm to .3mm, which are elongated subparallel to the gneissic foliation.



SAMPLE: CDS-24D

CLASSIFICATION: Biotite Paragneiss

MODAL	ABUNDANCES :	Biotite	35%
		Muscovite	15%
		Quartz	15%
		Oligoclase	10%
		Microcline	10%
		Sphene	7%
		Opaques	4%
		Kyanite	3%
		Zircons	1%

TEXTURES: This sample is characterized by the gneissic foliation developed by alternating biotite rich bands with sericitized feldspar bands. The biotite rich bands are subparallel and continuous across the sample. Biotite occurs as idioblasts ranging in size from .1mm to .7mm. They create a sublepidoblastic to decussate texture within each biotite band. The biotite idioblasts are intergrown with the oligoclase and microcline xenoblasts, and often contain zircon poikiloblasts.

Contained in the biotite bands are minor amounts of kyanite, opaques, and sphene. The sphene occurs as small, <.1mm, rhombic idioblasts, and as .4mm aggregates. It contains no apparent alterations, and cross cuts all other minerals present. The opaques are commonly found as intergrowths with the biotite idioblasts usually as rims.

The quartzo-feldspathic bands contain large xenoblasts of quartz, and sericitized oligoclase and microcline. Irregular contacts of these xenoblasts yields a sutured texture. Minor biotite is present in these bands as small, <.1mm idioblasts. The oligoclase and microcline have witnessed a period of sericitization. The sericite occurs as small, <.1mm idioblastic poikiloblasts in the feldspar xenoblasts. The accessory minerals that are found in the biotite rich bands are also found in the quartzofeldspathic bands.



Mag 10CX

SAMPLE: CDS-6B

CLASSIFICATION: Biotite-Chlorite Paragneiss MODAL ABUNDANCES : Biotite 25% 20% Oligoclase 20% Quartz 10% Chlorite Muscovite 10% 8% Kyanite Sphene 5% 2% Opaques

TEXTURES: The sample is characterized by alternating biotite rich, with quartzo-feldspathic bands. The banding is not continuous, and is poorly defined.

The biotite rich bands are essentially composed of idioblastic biotite with subidioblastic kyanite and chlorite. The biotite and chlorite are intergrown, and yield a decussate texture. They range in size from .1mm to .4mm. The kyanite ranges in size from .1mm to .6mm, and shows a symplectite texture with oligoclase xenoblasts.

The quartzo-feldspathic bands are composed of sericitized oligoclase and quartz xenoblasts, ranging in size from .1mm to .8mm. The contacts are irregular, yielding a distinct sutured texture. Extensive sericitization has occurred with the oligoclase xenoblasts. The sericite occurs as idioblasts ranging in size from <.1mm to .1mm.

Present in both types of bands, are the accessory

minerals, sphene and opaques. The sphene occurs as subidioblastic rhoms which vary in size from <.1mm to .4mm. It commonly cross cuts the other minerals, suggesting formation at a later time. The opaque minerals occur as xenoblasts, found at the ends of the chlorite-biotite intergrowths.



SAMPLE: CDS-3A

CLASSIFICATION: Olivine Skarn Xenolith MODAL ABUNDANCES: Forsterite 65% Calcite 15% Quartz 7% Sphene 5% Serpentine 5% Opaques 3%

TEXTURES: The sample is characterized by large fractured forsterite xenoblasts set in a calcite-quartz matrix. The forsterite ranges in size from .5mm to 3mm. The contacts are extremely irregular, with calcite commonly present along these contacts. Poikiloblasts of quartz and calcite are commonly found within these forsterite xenoblasts. The serpentine occurs as very small xenoblasts that are concentrated along the fractures within the forsterite xenoblasts.

Calcite is present in the sample as xenoblasts, ranging in size from .1mm to .3mm. Calcite nodules ranging in size from 1mm to 1.7cm are scattered throughout the sample. Radiating from these nodules are small veinlets of calcite which wind their way through the forsterite xenoblasts. The calcite xenoblasts show a symplectite texture with the forsterite. Around each calcite nodule are xenoblasts of forsterite and quartz. It is common to see some forsterite xenoblasts isolated within the calcite nodules. The quartz is present as xenoblasts ranging in size from <.1mm to 3mm. It is seen filling in cavities around the forsterite and calcite xenoblasts. A distinct undulating extinction characterizes these xenoblasts.

Sphene, and the opaque minerals are accessory minerals in this sample. The opaques occur as <.1mm xenoblasts that are restricted to the calcite nodule-forsterite xenoblast contacts. The sphene occurs as idioblasts ranging in size from <.1mm to .2mm. These idioblasts commonly crosscut crystal boundaries, and are not altered to any great extent.



SAMPLE: CDS-2C

CLASSIFICATION: Quartz Hornfels Xenolith

MODAL ABUNDANCES :

Quartz	25%
Muscovite	20%
Orthoclase	20%
Tremolite	10%
Microcline	8%
Vesuvianite	5%
Sphene	5%
Opaques	5%
Chlorite	<1%

TEXTURES: The sample is characterized by a high proportion of fine grained quartz and feldspar xenoblasts which range in size from <.1mm to .4mm. The quartz occurs as xenoblasts creating a sutured texture, and as poikiloblasts in the feldspar and tremolite xenoblasts.

The orthoclase and microcline occur as xenoblasts which have witnessed an intense period of seritization. Almost complete alteration and replacement by sericite-muscovite has occurred. The sericite occurs as subidioblasts ranging in size from <.1mm to .1mm. The sericitized feldspar xenoblasts are common as intergrowths with quartz and tremolite.

Muscovite is present as fibrous idioblasts ranging in size from .1mm to .4mm. These exclusively occur as radiating idioblasts that show a symplectite texture with the surrounding minerals. Tremolite is present as .4mm to .8mm xenoblasts. It is usually fractured, and contains poikiloblasts of quartz and feldspar. A symplectite texture is visible between the tremolite and sericitized feldspars.

Vesuvianite is present as small, hard to distinguish xenoblasts that are intergrown with the opaque minerals. A distinguishing anomalous blue birefringence can be clearly seen.

The accessory minerals, sphene, chlorite and the opaques make up 10% of the sample. Chlorite is present as an alteration product of the muscovite idioblasts. Sphene occurs as subidioblasts ranging in size from <.1mm to 1mm. It cross cuts all mineral boundaries, and is free of any alterations. The opaque minerals are varied in appearance. A definite cubic shape can be seen on amny opaque subidioblasts. Pyrite seems to be the main opaque mineral present. Opaques also occur as xenoblasts that have a rim of limonite around them. These opaque xenoblasts show a symplectite texture with the vesuvianite xenoblasts.



SAMPLE: CDS-23

CLASSIFICATION: Biotite-Muscovite Granite

MODAL	ABUNDANCES :	Orthoclase	30%
		Quartz	20%
		Albite	20%
		Muscovite	15%
		Biotite	10%
		Sphene	3%
		Zircon	1%
		Chlorite	1%

TEXTURES: The thin section is dominated by large anhedralgranular crystals of feldspar and quartz, with biotite, muscovite, and accessory sphene and chlorite. The albite occurs as anhedral crystals ranging in size from .1mm to 2mm, that form an interlocking texture with the quartz and orthoclase crystals. The albite has undergone a period of sericitization that has formed a poikilitic texture.

The orthoclase occurs as anhedral crystals ranging in size from .2mm to 2mm. It also shows sericitic alteration.

Quartz occurs as anhedral crystals ranging in size from .1mm to 1.5mm. It is present as interlocking crystals with the feldspars, and as inclusions within the subhedral biotite and muscovite. The quartz and feldspars commonly show a myrmekitic texture.

Around the contacts of the interlocking quartz and

feldspar crystals, biotite and muscovite crystals are found. These subhedral crystals r nge in size from <.1mm to .4mm. There is no preferred orientation to these biotite and muscovite crystals.

Chlorite, sphene and zircon occur as accessory minerals in this sample. The chlorite is present as fine grained xenoblasts that are intergrown with the biotite crystals. The zircons occur as subhedral inclusions with the biotite. Pleochroic halos are found around each poikilitic zircon.



SAMPLE: CDS-19

CLASSIFICATION: Muscovite Tonalite

MODAL	ABUNDANCES :	Albite	40%
		Muscovite	20%
		Quartz	20%
		Orthoclase	8%
		Calcite	8%
		Chlorite	3%
		Serpentine	1%

TEXTURES: This sample is characterized by the presence of severely sericitized feldspar xenoliths within a less altered albite, quartz and orthoclase matrix. These xenoliths contain albite and orthoclase crystals, that have been sericitized. Chlorite is found intergrown with the sericite. The xenoliths range in size from 1cm to 10cm in size. Quartz is found as anhedral crystals ranging in size from .1mm to .7mm.

The host rock is composed of anhedral albite, quartz, and orthoclase crystals ranging in size from .1mm to 2mm. These crystals show an interlocking texture. Minor muscovite and chlorite are present as inclusions within the quartz, albite, and orthoclase. The quartz is commonly found as inclusions within the albite, and as myrmekitic intergrowths. A distinct undulating extinction distinguishes the quartz from the albite and orthoclase.

There are two sets of calcite-serpentine filled

fractures that are found orthogonal to each other. These fractures contain fine grained (< .1mm) anhedral calcite and serpentine which cross cut all minerals in the sample. At the ends of these discontinuous fractures, larger, .1mm to .3mm anhedral calcite crystals are found.



APPENDIX B

RAW PETROCHEMICAL DATA

WHOLE ROCK ANALYSIS IN WEIGHT % OXIDES (UNNORMALIZED)

MARBLES CDS 5 35.8 12.1 24.8 4.26 0.39 1.64 7.92 0.04 0.60 0.09 3.77 91 CDS 2B 0.41 0.11 55.58 0.69 0.08 0.03 0.12 0.01 0.17 43.17 100 CDS 16C 8.4 0.48 27.4 18.6 0.10 0.13 0.58 0.05 0.02 0.03 41.65 97 AMPHIBOLITES AMPHIBOLITES A <th>UM</th>	UM
CDS 5 35.8 12.1 24.8 4.26 0.39 1.64 7.92 0.04 0.60 0.09 3.77 91 CDS 2B 0.41 0.11 55.58 0.69 0.08 0.03 0.12 0.01 0.17 43.17 100 CDS 16C 8.4 0.48 27.4 18.6 0.10 0.13 0.58 0.05 0.02 0.03 41.65 97 AMPHIBOLITES AMPHIBOLITES A	
CDS 2B 0.41 0.11 55.58 0.69 0.08 0.03 0.12 0.01 0.17 43.17 100 CDS 16C 8.4 0.48 27.4 18.6 0.10 0.13 0.58 0.05 0.02 0.03 41.65 97 AMPHIBOLITES	.41
CDS 16C 8.4 0.48 27.4 18.6 0.10 0.13 0.58 0.05 0.02 0.03 41.65 97 AMPHIBOLITES	• 37
AMPHIBOLITES	.44
CDS 12C 40.6 16.3 15.2 11.0 0.44 0.51 9.89 0.13 0.81 0.16 0.04 2.77 98	.4
CDS 13 47.2 17.6 9.41 6.49 3.06 1.29 11.1 0.16 0.79 0.20 1.70 99	.1
CDS 15 47.74 17.64 8.10 7.14 3.17 1.45 11.0 0.14 0.79 0.28 2.61 100	.06
PARAGNEISS '	
CDS 9 58.9 15.4 3.36 2.78 2.44 2.41 5.16 0.01 0.91 0.06 0.01 1.93 98	.4
CDS 6B 56.3 17.0 7.36 2.89 2.49 1.72 6.64 0.05 0.77 0.12 0.01 3.54 99	.0
CDS 24 74.8 10.2 1.82 1.34 2.30 2.61 3.24 0.04 0.58 0.09 0.01 0.93 99	.1
XENOLITHS	
CDS 4A 45.3 16.7 15.5 6.18 1.82 0.60 9.51 0.12 0.73 0.15 1.85 98	.6
CDS 3A 41.4 16.6 20.2 5.20 0.27 0.13 11.6 0.21 0.69 0.16 0.01 1.93 98	•5
CDS 2C 57.5 16.4 5.36 2.89 3.81 3.13 6.59 0.12 0.70 0.23 2.47 99	.2
GRANITIC BODIES	
CDS 19 72.7 14.7 1.50 0.87 4.75 2.13 1.10 0.01 0.11 0.03 0.01 1.62 99	.6
CDS 23 77.1 11.0 1.18 0.73 1.72 4.97 1.16 0.02 0.17 0.02 0.02 1.00 98	