Metamorphism of the George River Group;
Gold Brooks, Victoria County
Cape Breton Island, Nova Scotia

by

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ABSTRACT

The Precambrian George River Group of Cape Breton Island, Nova Scotia is characterized by metasediments and metavolcanic rock types.

A sequence of predominantly feldspathic quartzites slates and quartzites at Gold Brooks has been deposited in an offshore environment. During deposition, recurrent mafic tuffs and lavas have interrupted the sequence producing thin interbands of mafic and felsic material with occasionally more massive units of these types.

Burial was followed by granitic intrusion during the Cambrian. The sequence has undergone at least one period of regional metamorphism, this being the Acadian orogeny. The regional metamorphic grade in the study area is observed to increase to the NNW from upper greenschist to middle amphibolite facies.

The intrusion of gold-bearing quartz veins in one location within the section has produced a wall-rock alteration which extends approximately 5 cm. from the vein.

A zone of middle greenschist facies metasediments occurs anomalously in Second Gold Brook, apparently associated with the mineralization, though no mechanism for this apparent retrograde metamorphism has been recognized.

Chapter 1 Introduction

(a) Regional Setting

The study area, which lies entirely within the George River Group, is located approximately three and a half kilometres east of the junction between the Cabot Trail, and the boundary between Inverness and Victoria Counties, Cape Breton Island (Figure 1).

From the Cabot Trail access is generally good via farmer's roads which extend into Second Gold Brook. The area is covered by thick mixed woods, and traversing is primarily restricted to stream beds. The relief is often very steep.

The Geology of the area is characterized by the metamorphosed George River Group, which has been intruded by granitic plutons of Cambrian age (Cormier 1972). Erosion of these rocks has produced the Carboniferous Horton Conglomerates, which now exist only in the lowlying areas.

(b) Purpose

The George River Group has undergone extensive regional and, in some locations, contact metamorphism. This report will deal with the petrographic and geochemical aspects of these changes, by examination of a suite of George River rocks at Gold Brooks.

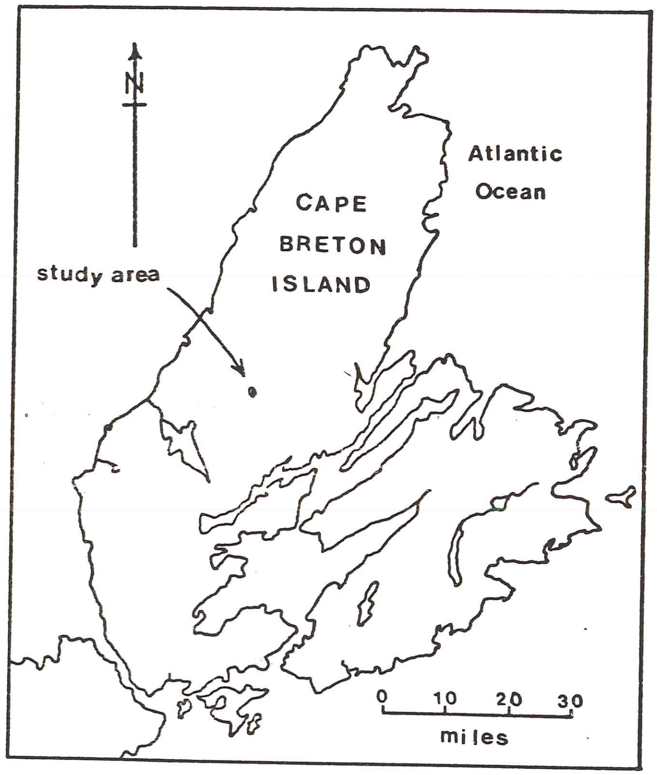


Figure 1: Location of study area, Cape Breton Island, Nova Scotia

The study area was chosen because Milligan suggested that the fault plane of a major thrust sheet of George River rocks may outcrop within the section (personal communication, 1978). If this is so, then changes in the profile of the metamorphic grade may delineate its position. The absence of the above will be taken as negative evidence of such a structure in this area.

The purpose of this thesis is then to:

(1) determine the grade of metamorphism (both regional and contact)

by: a) mineral assemblages.

b) geothermometry/geobarometry of coexisting phases.

c) mineral chemistry and texture.

(2) examine the evidence for a large scale, low angle, thrust fault.

(3) determine a protolith for the amphibolitic rocks in the section.

(4) propose a model to account for the present assemblages.

(c) Previous Work

Relatively little detailed mapping has been done in the George River Group. Predominantly, it has been mapped as a single unit, separating it form the Carboniferous rocks in Cape Breton, which are currently of more economic interest.

The first work done in the area was large scale mapping by Fletcher of the G.S.C. in the late 1800's. More detailed work was carried out in the Gold Brooks Area at the turn of the century, when a gold mine came into operation on Second Gold Brook. Since that time, Kelley (1952) did extensive work in the George River Group for the G.S.C.

Drilling and electromagnetic surveys were carried out in the vicinity of the mine on Second Gold Brook by Cape Breton Metals in 1955, and Mareast Exploration in 1962, with the hope of new prospects being found.

Detailed mapping was performed by Milligan (1970) for the N.S. D.M. throughout much of the George River Group, including the Gold Brooks district.

Chapter 2 Field Work

(a) Procedures

Field work was carried out over a period of five days, with the assistance of Dr. D.B. Clarke, Dr. G.C. Milligan and P.L. Mitchell. Detailed mapping was performed along Second Gold Brook, a section of Middle River, and Falls Brook* (Map 1), previously mapped on a larger scale by G.C. Milligan and Brian White in 1966.

The section is at right angles to the regional strike, and has a linear extent of approximately two and a half kilometres. Streams were mapped by the "Parsons Technique" (Milligan 1970), with stream intersections being used for control points. The outcrop is almost continuous and samples were collected at least every thirty metres. In the immediate vicinity of Middle River, outcrop is poor to absent, so that continuous sampling was not possible. In areas of interest, or more complex geology, samples were more closely spaced.

All data were recorded in notebooks, and transferred to Nova Scotia Lands and Forests Base Maps (1:15,840) once field work was completed. Photographs were taken of lithologies and structures. Topographic sheets, 1:150,000 scale (N.S. 11K/2 and 11K/7), and N.S. D.M. Memoir #7 (Milligan, 1970) geology sheets were used for locating in

*Falls Brook is not an accepted label, but was given to the un-named brook for the purpose of reference in the field. The name alludes to the abundant waterfalls present along its length.

the field and drawing of the maps.

(b) Field Relations (refer to Figure 2 and 3)

The section is characterized by amphibolitic, semi-pelitic, and psammitic rocks of the George River Group.

The northern most end of the section, a contact between coarse-grained granite and a gneiss (Photo 1), occurs near the head of Falls Brook. No chilling of the granite is observed. After twenty metres (lateral thickness), the gneiss passes into a three-metre-wide shear zone (Photo 2), which grades into amphibolites.

The amphibolites vary in texture, from coarse to fine, and massive to foliated. Hornblende amphibolite is interbedded with quartzites, and both lithologies range from about one centimetre to twenty metres in thickness, with both contacts gradational (Photo 3 and 4). No primary tops could be determined. The amphibolite-quartzite unit contains several bands of fissile slate, commonly 10-80 cm. in thickness, and is cut by randomly-oriented quartz veins of 2-20 cm. This ampbhibolite-quartzite unit extends to at least the centre of the Middle River section. The unit dips from 35° to 60° to the NNW.

Second Gold Brook is characterized by metapsammites and metapelites, predominantly quartzites, feldspathic quartzites, and grey slates. The lower half of Second Gold Brook consists of intergrading units of mica-chlorite schist and quartzites. A unit of coarse quartz conglomerate (Photo 5) approximately 15m thick (neither contact observed),

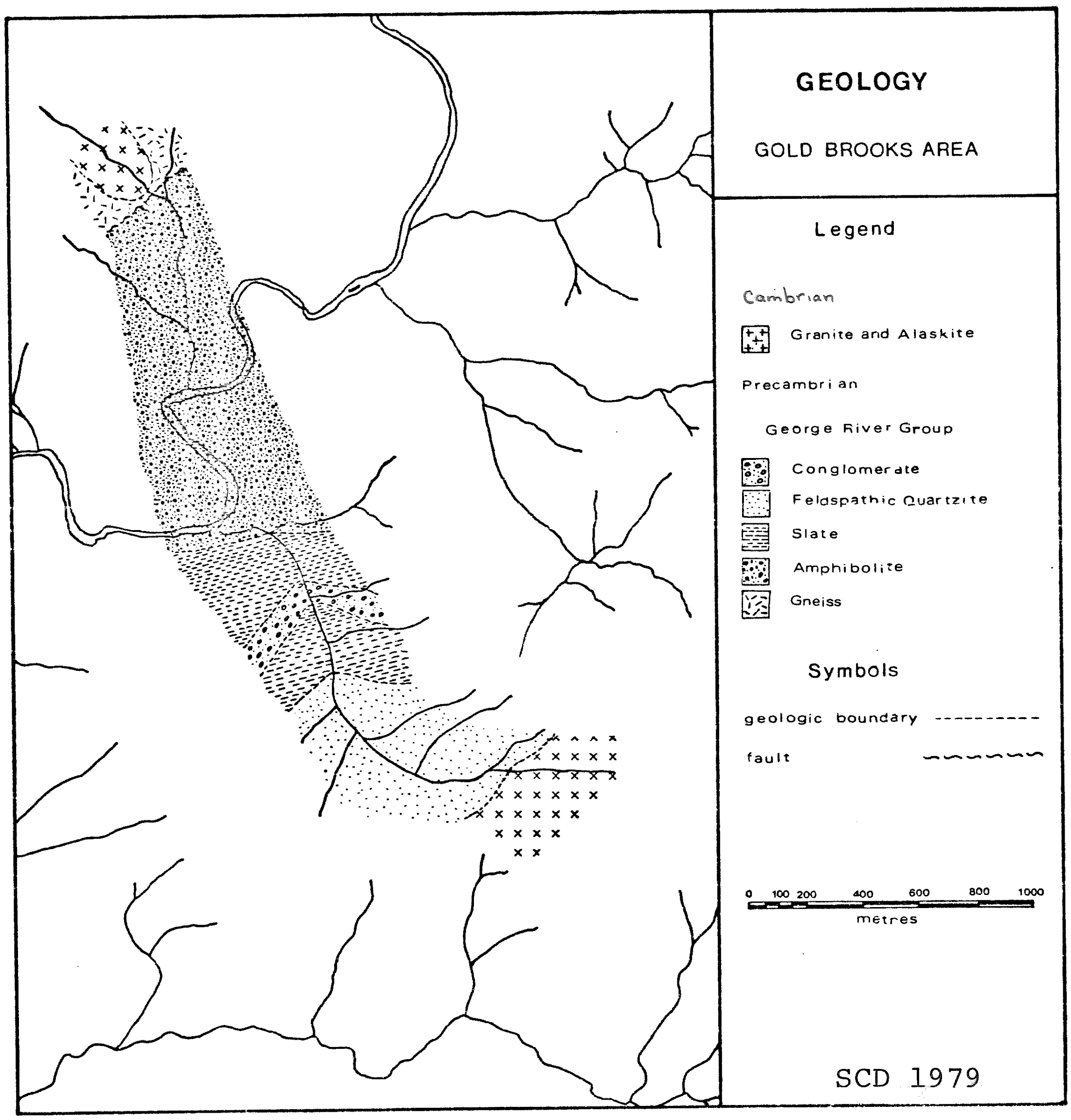


Figure 2: Geology of Gold Brook Area - geology only indicated for section mapped in this study.

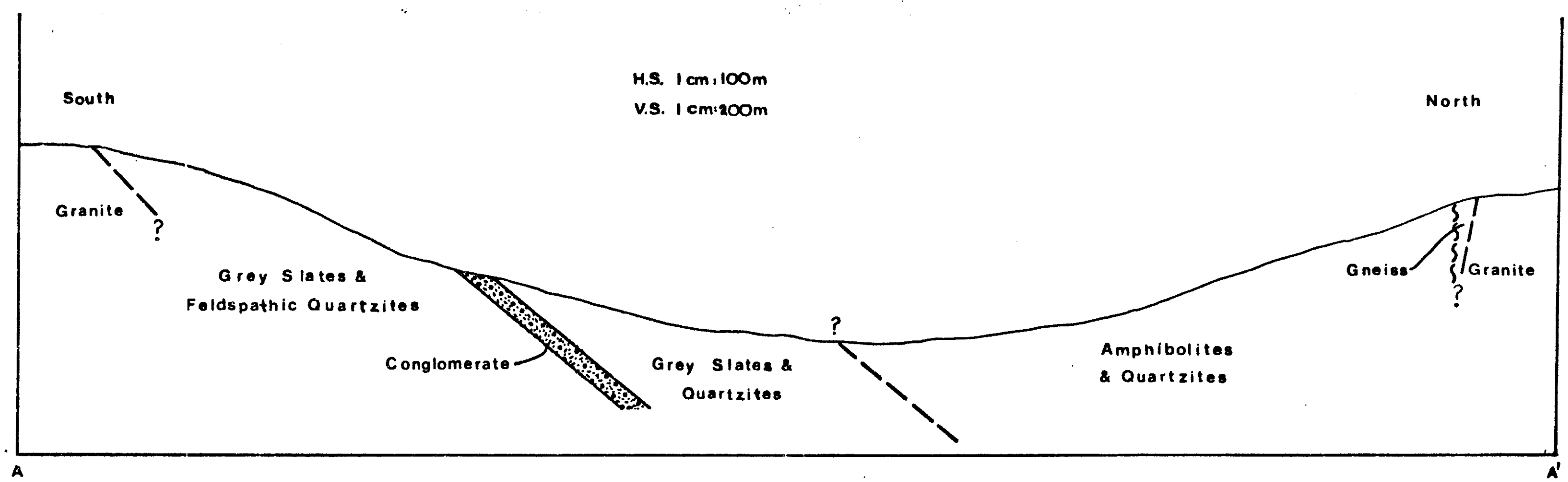


Figure 3: Simplified Cross-section at Gold Brooks
- position of contacts at depth is uncertain.

begins about 150 metres upstream from the farm road. In the vicinity of the mine, chlorite schist becomes the dominant lithology. Upstream from the mine are grey slates (Photo 6) and schists of quartz, feldspar and micas. The upper half of Second Gold Brook is predominantly feldspathic quartzite. The dip is generally to the NNW and steepens gradually from 30° to 70° upstream. At the head of Second Gold Brook is an intrusion of alaskite. The contact is not visible. Milligan (1970) proposed that the area is underlain at shallow depth, less than 75 m. by intrusives.

Photograph 1. Contact between Granite and Gneiss - Falls Brook; SD88/SD89.

Photograph 2. Shear Zone- Falls Brook; SD-86.

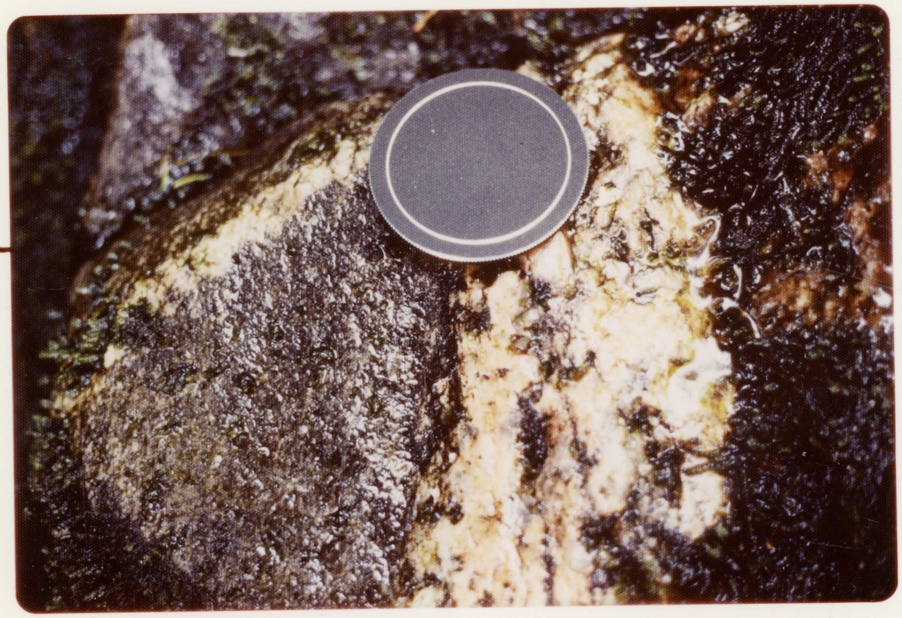


PHOTO 1

PHOTO 2

Photograph 3. Interlayered Amphibolite and Quartzite - Falls Brook;

Photograph 4. Bands of quartzite in Amphibolite - Falls Brook; SD-70.

PHOTO 3

PHOTO 4

Photograph 5. Conglomerate - Second Gold Brook; SD-21.

Photograph 6. Grey Slate - Second Gold Brook; SD-36.

PHOTO 5

PHOTO 6

Chapter 3 General Petrology

The Gold Brooks section is composed of psammitic, pelitic, and amphibolitic rocks which are bounded by intrusive bodies. The general petrology of the rock types is described here, while a more detailed description can be found in Appendix A.

Units Present

A. Metamorphic Rocks

1. Conglomerate
2. Feldspathic Quartzite
3. Chlorite-Mica Schist (Slate)
4. Quartzite
5. Amphibolite

B. Intrusive Rocks

1. Alaskite
2. Granite

A.1. Conglomerate

Conglomerate occurs only in one place in the section, as a band, 15 m. thick, below the old mine site on Second Gold Brook. The unit is red-grey in colour. Pebbles, commonly of quartz, are well rounded, elongate, and comprise up to 40% of the unit. Their average size on exposed surfaces is 10 x 3 cm., though some have been flattened to as much as 20 x 2 cm. The matrix is fine-grained and resembles the slates above and below the conglomerate. The source of the conglomerate is unknown.

A.2. Feldspathic Quartzite

Feldspathic quartzites characterized by the presence of quartz, feldspars and micas are found in the upper portion of Second Gold Brook. They are dark brown to pinkish-grey, medium grained, and show a foliation tending towards banding which coincides with the bedding. Relict grains of plagioclase are evident in most samples though their presence varies within the unit. Usually foliated or massive, these feldspathic quartzites sometimes develop an augen-like texture due to the presence of relict grains at the time of metamorphism (Photo 7).

A.3. Slate

Very fine-grained, light green-grey slates occur in the lower half of Second Gold Brook. They exhibit good cleavage,producing layers less than 1 cm. thick, which are coincident with the bedding. High contents of chlorite and muscovite give the slates a greenish tone and a very fissile nature. The presence of almandine, chloritoid, magnetite and chlorite porphyroblasts in different layers, probably reflects variation of rock chemistry within the unit. The slates, which are cut by quartz veins in the vicinity of the mine, are extremely rich in chlorite. (Photo 8).

Photograph 7. Lenticular relict grains in banded feldspathic quartzite; SD-54, PPL, x12.

Photograph 8. Chorite Schist; SD-27, PPL, x50.

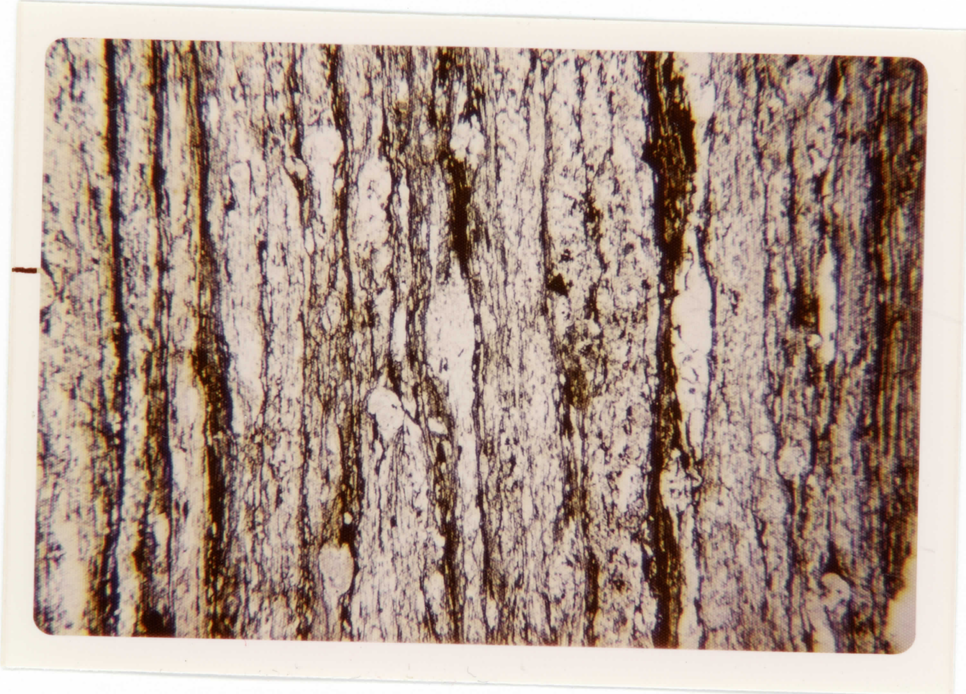


PHOTO 7

PHOTO 8

A.4. Quartzite

Quartzites grade into the feldspathic quartzites and the slates, and are also interbedded within these other units. They are massive, dark-coloured, fine-grained rocks, showing minor foliation or merely a granoblastic texture. Quartzites are also found interbedded with the amphibolites, but these will be discussed separately, with the amphibolites.

A.5. Amphibolites

Interbedded amphibolites and quartzites are found along Falls Brook, Middle River and the lowest portion of Second Gold Brook. The amphibolites are composed primarily of tschermakitic hornblende (classification after Leake, 1978), plagioclase (oligoclase to andesine) and quartz. The overall texture is dependent upon the amphibole, which ranges from coarse-grained prismatic to acicular. Commonly the amphibolites also contain biotite and ilmenite. Some may have epidote, calcite or chlorite. One sample, SD-14B contains almandine, which with biotite will be used as geothermometer, employing partitioning of iron and magnesium (Ferry and Spear, 1978). Hornblende varies in colour from light brown to blue-green. The quartzites have a similar mineralogy but since they contain no amphibole and little biotite, the foliation is less evident. (Photos 9-11).

Photograph 9. Amphibolite, almandine coexisting with biotite and hornblende, subhedral crystals; SD-14B, PPL, x30.

Photograph 10. Fine foliated amphibolite; SD-72, PPL, x30.

PHOTO 9

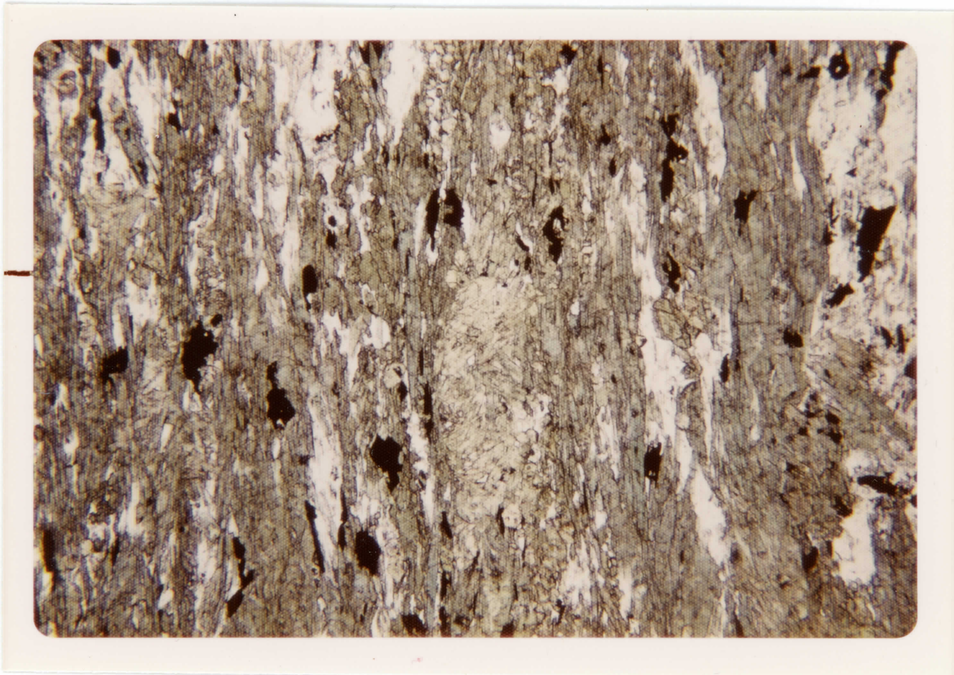


PHOTO 10

B. Intrusive Rocks

The intrusives in the vicinity of Gold Brooks are granites, syenites, and alaskites, all believed to be differentiates from a common magma (Milligan, 1970).

B.1. Alaskite

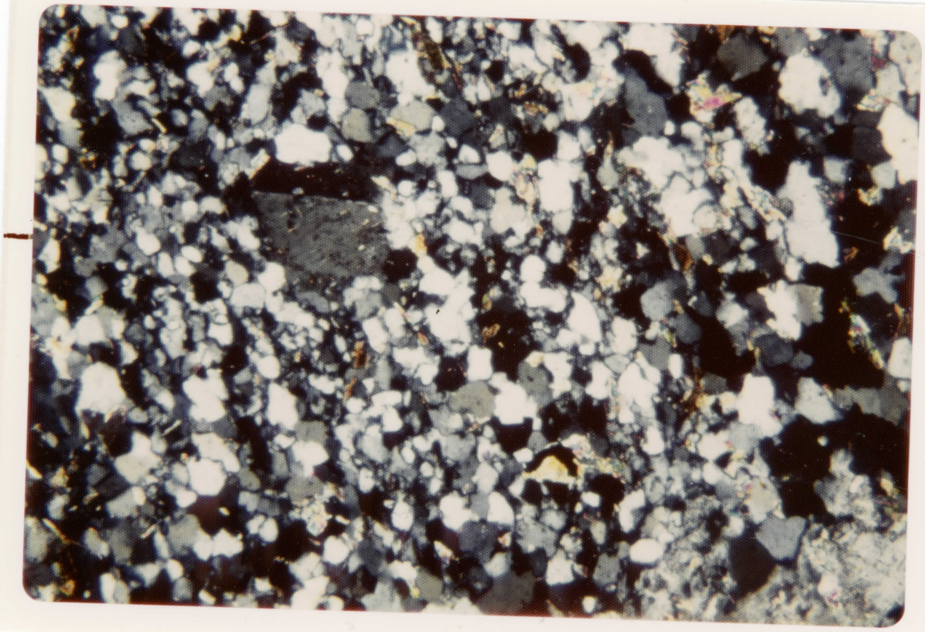
At the head of Second Gold Brook, an alaskite shows a rhyolitic texture as a marginal phase. This pinkish, medium-grained, banded rock is very similar in texture and mineralogy to the feldspathic quartzites which it intrudes. The mineralogy is dominantly quartz, with orthoclase and albitic plagioclase, minor muscovite is observed close to the contact where extensive brecciation is visible. (Photo 12).

B.2. Granite

At the head of Falls Brook, a pod of granite, coarse-grained in nature, and composed of quartz orthoclase and plagioclase is in contact with a gneiss. Plagioclase crystals form algomerates and are complexly twinned. Large quartz grains show undulose extinction. (Photo 13).

Photograph 11. Quartzite from amphibolite unit; SD-71, XN, x50.

Photograph 12. Altered recrystallized rhyolite; SD-62, PPL, x20.



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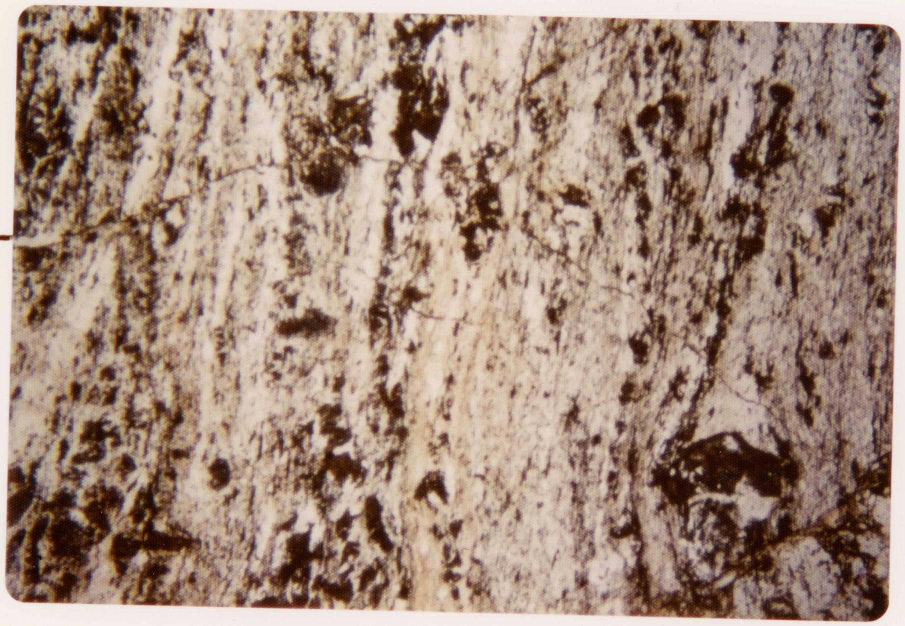
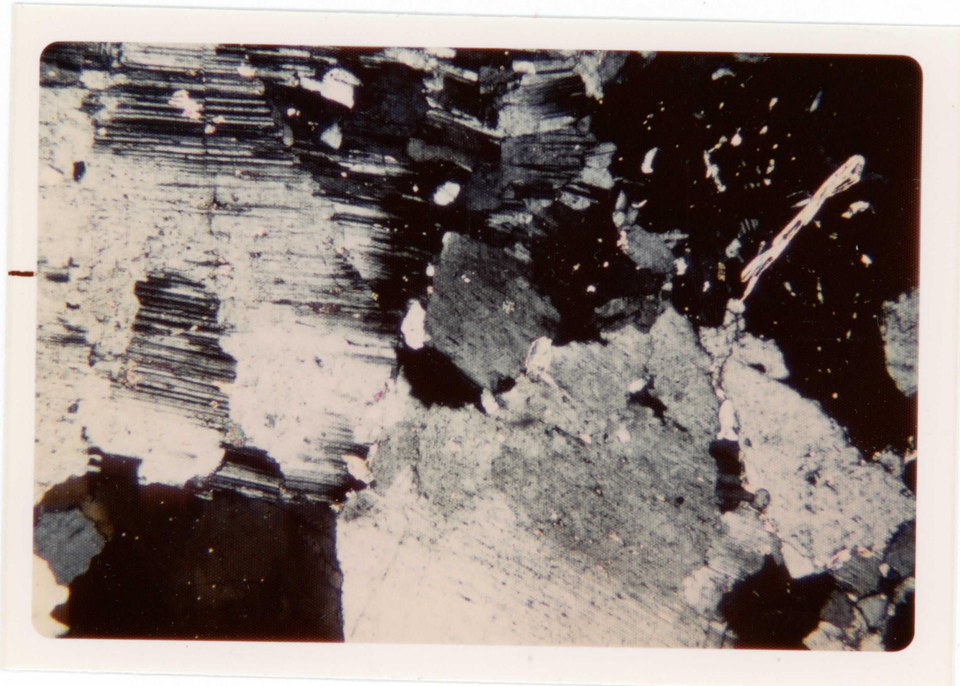


PHOTO 12

Photograph 13. Granite, broken and bent plagioclase grains, undulose extinction; SD-89, XN, x31.



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Chapter 4 Geochemistry

(a) Whole-Rock Geochemistry

Representative samples from different units and locations were selected for whole-rock analyses. Rocks were cleaned, powdered and then fused to form homogeneous glass beads which were then analysed by electron microprobe. The results are presented in Table 1.

The mineralogy is closely related to the whole-rock geochemical analyses. The amphibolites are rich in FeO, Fe_2O_3, MgO, MnO and CaO while depleted in SiO_2 and K_2O in comparison with the quartzites, feldspathic quartzites and the gneiss.

ACF and AFM diagrams have been plotted for the analysed samples as well as minerals of variable composition (hornblende, biotite and garnet) (Figures 4,5 and 6). Samples SD-49 and SD-55 belong to the greenschist facies and are therefore plotted with the assemblage for this facies. Sample SD-36 is a non-equilibrium assemblage. The remaining whole-rock analyses are plotted with amphibolite facies assemblages. The assemblages on these diagrams closely correlated with those observed in the samples. (See slide descriptions, Appendix A.)

Five hornblende compositions have been plotted, four of which are closely spaced in the hornblende field. The fifth, SD-67, has been partially chloritized and plots toward the composition of chlorite. Biotite and garnet from SD-14B have also been plotted. The biotite is rich in iron and/or magnesium and the garnet is not pure almandine but rather a solid solution with grossularite. The AFM plot (Figure 6)

Table #1 WHOLE-ROCK ANALYSES - WEIGHT PERCENT OF MAJOR OXIDE

OXIDE	SD 1	Sd 16	SD 36	SD 49	SD 55
SiO_2	77.6	67.6	65.7	53.0	62.0
TiO_2	0.5	0.7	0.8	1.6	0.9
Al_2O_3	12.6	18.5	19.5	17.5	18.3
Fe_2O_3*	0.4	0.2	0.8	1.5	0.7
FeO	2.3	1.6	4.5	8.6	3.7
MnO	0.0	0.0	0.0	0.1	0.0
MgO	0.6	1.3	2.1	3.7	1.5
CaO	0.9	2.2	0.2	8.9	0.6
Na_2O	4.0	3.9	1.5	3.8	4.9
K_2O	1.4	2.6	4.6	0.8	6.3
total	100.3	98.6	99.6	98.9	98.8

OXIDE	SD 67	SD 68	SD 75	SD 81	SD 83	SD 87
SiO_2	43.8	49.8	45.4	72.6	52.4	63.0
TiO_2	4.5	2.3	4.3	0.4	2.3	0.5
Al_2O_3	13.3	16.9	15.4	13.3	15.1	20.0
Fe_2O_3	2.7	1.6	2.2	0.5	1.0	0.5
FeO	15.2	9.1	12.3	2.8	5.9	3.1
MnO	0.3	0.1	0.3	0.0	0.1	0.1
MgO	7.1	6.9	8.4	0.2	7.8	1.4
CaO	8.5	9.1	8.9	3.6	10.1	3.6
Na_2O	3.2	3.1	2.9	2.1	1.7	5.1
K_2O	0.6	0.5	0.3	3.3	0.5	2.1
total	98.9	99.2	100.2	98.7	96.8	99.4

*Fe_2O_3 arbitrarily calculated from total iron as FeO so that

$Fe_2O_3/[FeO + Fe_2O_3] = 0.15$

SD 1	quartzite - from amphibolite unit; Falls Brook
SD 16	quartzite - from amphibolite unit; Falls Brook
SD 36	quartzite; Second Gold Brook
SD 49	feldspathic quartzite; Second Gold Brook
SD 55	feldspathic quartzite; Second Gold Brook
SD 67	amphibolite; Middle River
SD 68	amphibolite; Falls Brook
SD 75	amphibolite; Falls Brook
SD 81	quartzite - from amphibolite unit; Falls Brook
SD 83	amphibolite; Falls Brook
SD 87	gneiss; Falls Brook

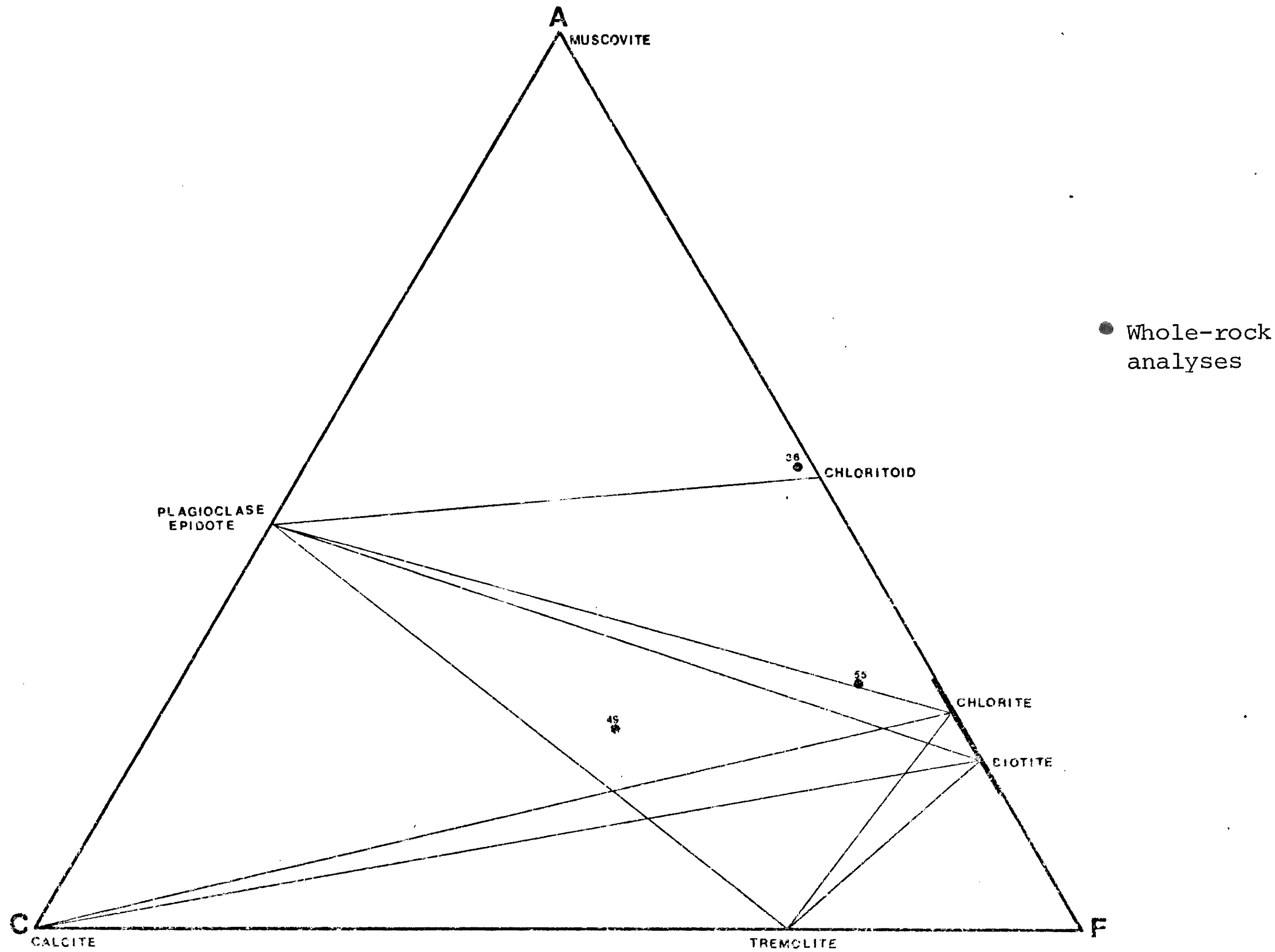

Figure 4. ACF plot of whole rock analyses for greenschist facies (SD49, epid, plag, qtz, trem, chl; SD55, qtz, hem, plag, chl; SD36, non equilibrium assemblage, plag, qtz, chl, bio, musc).

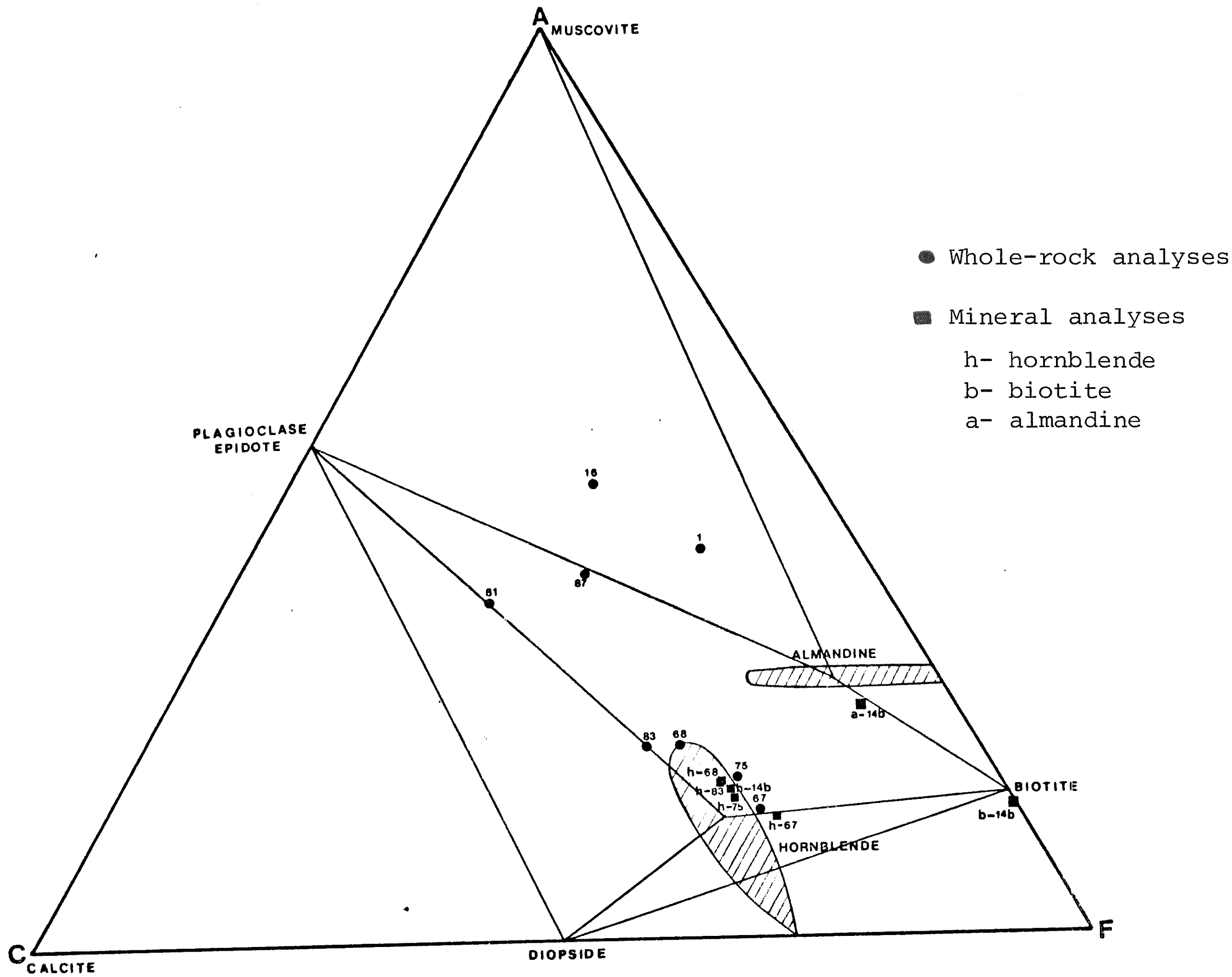

Figure 5: ACF plot of whole-rock and mineral analyses for amphibolite facies samples (SD 1, qtz-plag, hbl; SD 16, qtz, plag; SD 68, hbl, qtz, plag, bio; SD 75, hbl, qtz, plag, bio; SD 81, qtz, plag, mg; SD 83, hbl, qtz, plag, bio; SD 87, qtz, plag, bio). a-14b has grossular and spessartine components. h-67 is partially chloritized.

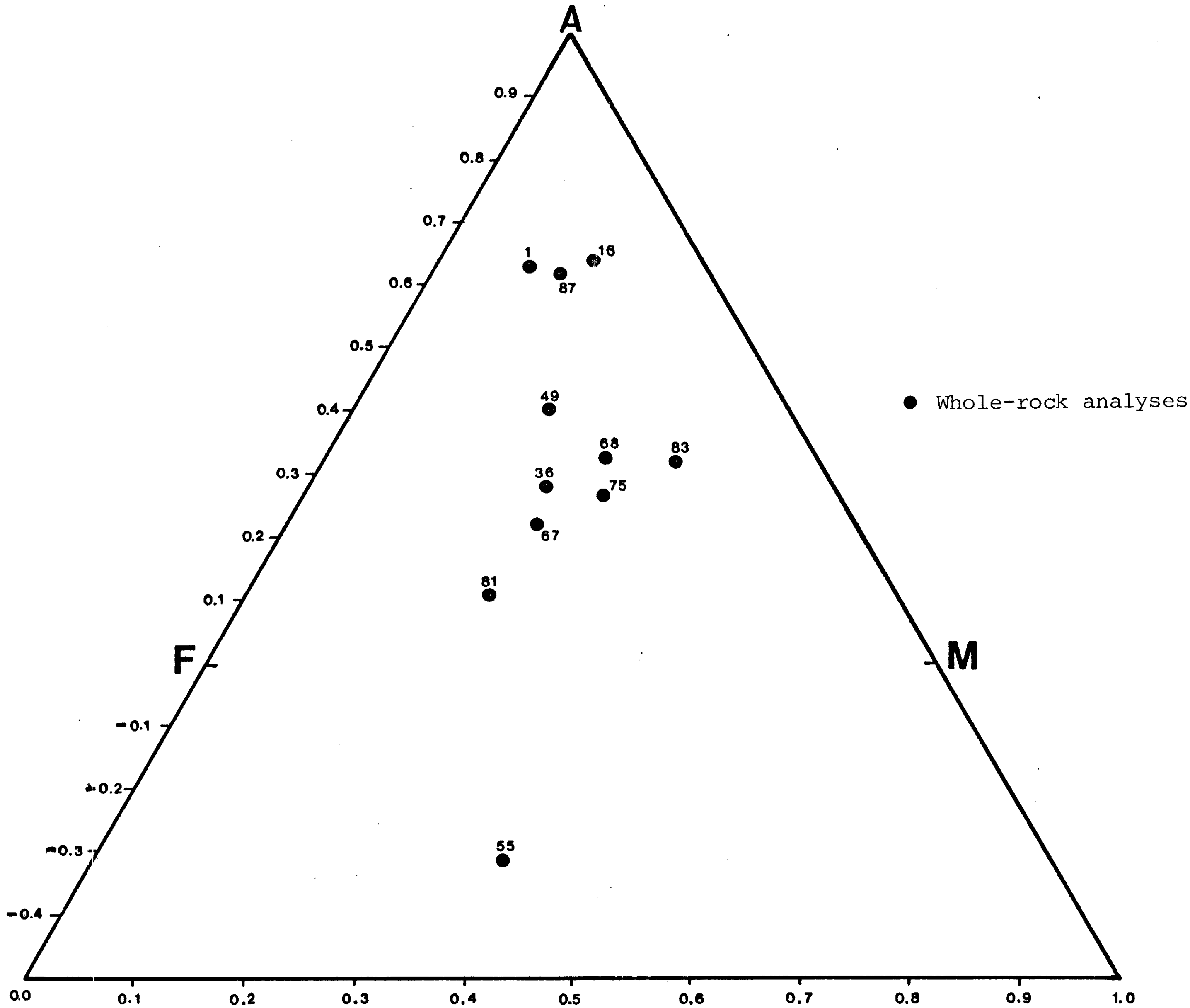

Figure 6: Whole-rock analyses plotted on AFM diagram.

negative A. SD-55 is rich in potassium fieldspar while SD-1, SD-16 and SD-87 are rich in alumina by comparison to potassium.

Normative compositions, calculated from the whole-rock analyses, according to C.I.P.W. rules (Barth 1962) are shown in Table 2.

The amphibolites contain no normative quartz, with the exception of SD-83. In fact, SD-67 is nepheline normative.

Amphibolites SD-67, SD-68 and SD-75 are distinctly more basic as they are highly olivine normative.

(b) Mineral Chemistry

1. Hornblende

Electron microprobe analyses of hornblendes from five different samples are shown in Table 3. The amphibole present has been classified as tschermakitic hornblende according to the system of Leake (1978). This means that when calculated on a basis of 24 oxygens; $(Ca + Na) > 1.34$, $(Na+K) < 0.50$, $Ti < 0.50$, $Mg/(Mg+Fe) \simeq 0.56$ and $Si \simeq 6.3$.

Sample SD-67 is appreciably more iron rich than the other four samples. It is a blue-green hornblende while the others are all green hornblendes.

2. Opaques

Ilmenite is the opaque phase present in the amphibolitic unit whereas magnetite is the phase in all other rock types. Minor pyrite

	SD1	SD16	SD36	SD49	SD55	SD67	SD68	SD75	SD81	SD83	SD87
Q	44.6	28.0	33.3	1.4	3.7				38.5	8.5	14.4
OR	8.3	15.6	27.6	4.8	37.7	3.6	3.0	1.8	19.8	3.1	12.6
AB	33.7	33.5	12.9	32.4	41.9	21.7	26.4	24.4	18.0	14.9	43.9
AN	4.4	11.1	1.0	27.5	3.0	20.3	30.9	28.0	17.3	33.1	18.2
NE						3.0					
DI				14.3		18.4	11.9	13.1	0.7	14.9	
HY	4.6	4.9	11.8	14.4	8.6		15.2	2.0	4.3	19.5	6.4
OL						20.4	5.9	19.4			
MT	0.6	0.3	1.2	2.2	1.0	4.0	2.3	3.2	0.8	1.5	0.7
IL	1.0	1.4	1.4	3.1	1.7	8.6	4.4	8.1	0.8	4.5	1.0
C	2.9	5.3	10.8		2.4						2.8

Table 2. C. I. P. W. Normative Analyses - Weight percent Normative Minerals.

OXIDE	SD-68	SD-67	SD-75	SD-83	SD-14B
SiO_2	42.9	41.0	43.7	43.0	41.2
TiO_2	0.4	0.3	0.5	0.5	0.3
Al_2O_3	16.3	13.6	14.8	16.0	14.2
FeO*	15.8	21.1	15.9	15.6	20.7
MgO	9.7	8.5	10.4	9.7	6.2
CaO	11.8	10.4	11.7	11.6	11.0
Na_2O	1.3	1.6	1.4	1.3	0.3
K_2O	0.4	0.4	0.4	0.3	1.1
total	98.6	96.9	98.8	98.0	96.0

* Total iron as FeO

Table 3. Amphiboles - Weight Percent of Major Oxides.

is found throughout the section.

Ilmenite has TiO_2/FeO^* from 1.10 - 1.12 except for SD-67 where the ratio is 1.01.

3. Feldspar

The anorthite content of plagioclase feldspars is observed to be very dependent upon the metamorphic grade. Increasing regional metamorphism causes an increase in the Ca component, and a sudden jump from albite (An_{0-7}) to oligoclase-andesine (An_{15-35}) because of a miscibility gap (Noble, 1962).

Electron microprobe data from six samples, and optical determinations,show the feldspathic quartzites in Second Gold Brook to contain albitic plagioclase while amphibolites and the gneiss in Falls Brook contain plagioclase in the oligoclase - andesine range. (Table 4)

Relict grains of plagioclase in the feldspathic quartzites which were originally calcium-bearing ($> An_7$) have broken down to albite and epidote. Those which show no associated epidote must have already been albite.

(c) Geothermometry

It has been shown (Ferry and Spear (1978), Goldman and Albee (1977)) that the portitioning of magnesium and iron between biotite and garnet which exist in an equilibrium assemblage can be used to determine the

Table 4. Feldspar Analyses

Component	SD42	SD49	SD67	SD68	SD75	SD87
Orthoclase	12.13	0.34	0.34	0.51	0.45	2.76
Albite	86.45	99.04	79.06	67.60	73.53	72.06
Anorthite	1.42	0.62	20.59	31.89	26.01	25.18

SD-42 feldspathic-quartzite; Second Gold Brook

SD-49 feldspathic-quartzite; Second Gold Brook

SD-67 amphibolite; Middle River

SD-68 amphibolite; Falls Brook

SD-75 amphibolite; Falls Brook

SD-87 gneiss; Falls Brook

temperature at which these mineral phases were last at equilibrium.

Figure 7 shows a polythermal, isobaric plot relating the partioning of Fe and Mg to the temperature of equilibrium. The partioning coefficient ln K=

ln [(Mg/Fe) garnet/(Mg/Fe) biotite].

Ferry and Spear (1978) stress that caution should be used in applying the data of systems containing significant amounts of Ca, Mn, or Ti. The rock sample used in this work is known to be rich in calcium and titanium.

Microprobe data from SD-14B shows the ratio of metallic magnesium to iron to be 0.349 for the biotite and 0.060 for the garnet. This yields a value of 0.172 for K. By plotting this result on Figure 7, the Ferry and Spear line gives a temperature of 554°C.

That garnet has been seen in only one sample within the unit, does not mean the sample is from a zone which has undergone different metamorphic conditions. Yoder (1951) states that the presence of garnet is related to the rate of growth, not the attainment of a particular temperature and pressure, though garnet chemistry is dependent upon these conditions. The presence of garnet is also very much controlled by the bulk chemistry of the rock.

Table 5. SD-14B Garnet-Biotite Analyses.

OXIDE	BIOTITE SD-14B OXIDE WT %	GARNET SD-14B OXIDE WT %
SiO_2	36.20	36.20
TiO_2	1.56	0.00
Al_2O_3	17.23	20.03
FeO*	23.68	31.29
MnO	0.09	4.80
MgO	10.66	2.08
CaO	0.12	4.30
Na_2O	0.00	0.00
K_2O	7.71	0.00
total	97.25	98.70

* total iron as FeO

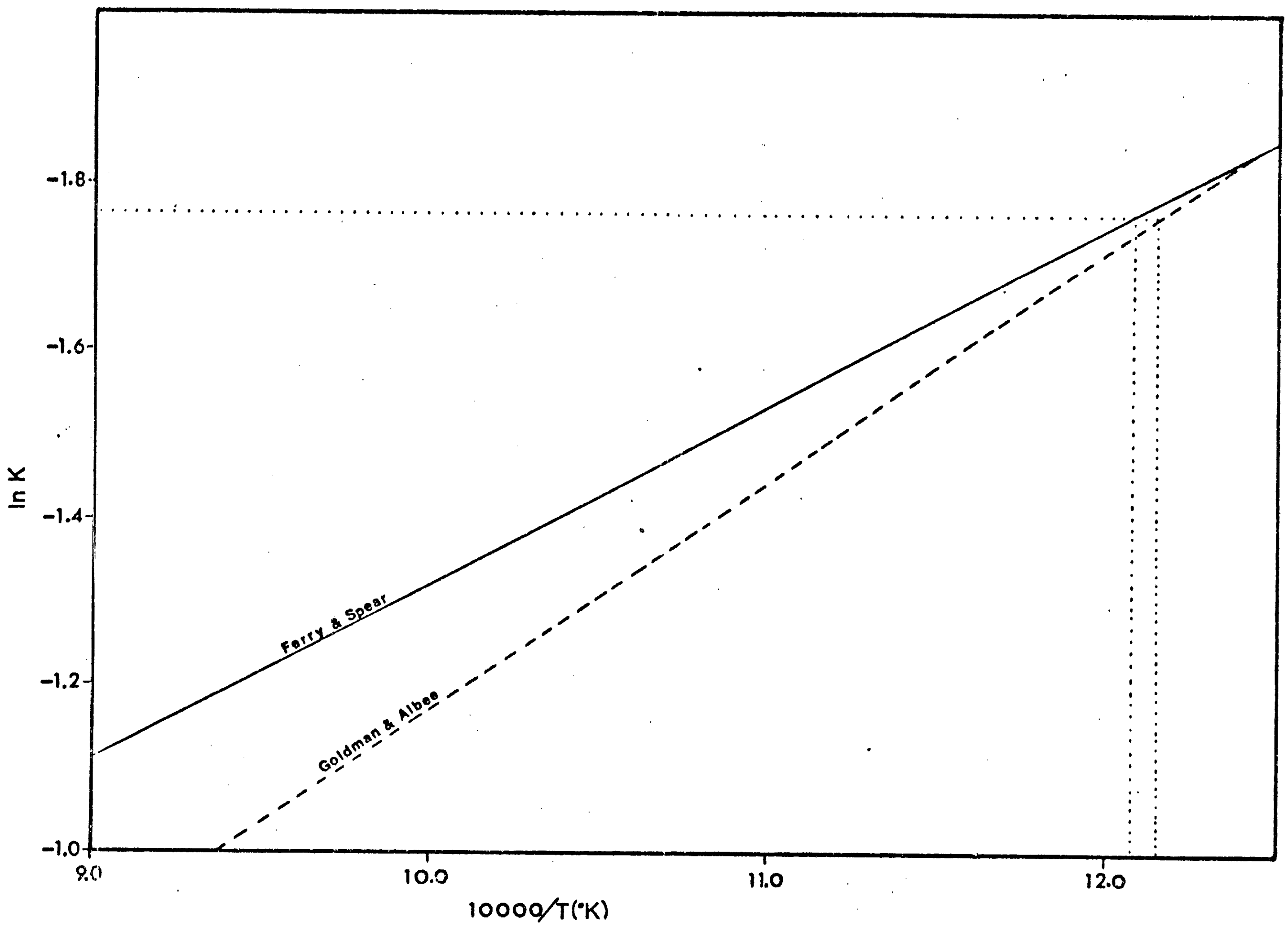

Figure 7: Garnet-biotite geothermometer. Plot of
ln K = ln [(Mg/Fe) garnet (Mg/Fe) biotite]
vs. 10.000/T(°K)

Chapter 5 Discussion

(a) Metamorphism

1. Degree of Metamorphism

By examination of approximately one hundred thin sections and hand samples, rocks from the study section have been placed into appropriate metamorphic facies. The rocks have been classified as either greenschist or amphibolite facies, and further subdivided into upper, middle, and lower, whenever possible. Many regional metamorphic classifications found in the literature tend to overlap and contradict one another, so assemblages are specified for the different metamorphic grades in the appropriate rock types (Table 5).

The alaskite and feldspathic quartzite in Second Gold Brook, have an assemblage of upper greenschist grade. The slates, also in Second Gold Brook, appear to be of middle greenschist facies. The absence of staurolite or andalusite precludes the possibility of their being in the amphibolite facies. The grade in Second Gold Brook shows a slight increase southward toward the intrusive. Southward, within the feldspathic quartzite unit, relict grains of plagioclase feldspar become more strained, and due to partial recrystallization more poikilitic. Recrystallization itself becomes more extensive.

Chlorite-epidote schist,in the lower end of Second Gold Brook, is believed to be an upper greenschist equivalent of the amphibolitic unit, because of the presence of calcite (25%), chlorite (15%), biotite

Table 6. Regional Metamorphic Assemblages

Assemblage	Metamorphic Facies			
	Greenschist		Amphibolite	
	Middle	Upper	Lower	Middle
Basic*	Albite, Epidote, Chlorite (Actinolite, Calcite, Quartz, Sphene).	Albite, Epidote, Actinotite (Chlorite, Quartz, Biotite, Calcite).	Blue-green Hornblende, Oligoclase-Andesine, Epidote (Quartz, Almandine, Biotite, Chlorite, Calcite).	Green Hornblende, Oligoclase-Andesine, (Quartz, Biotite, Almandine, Ilmenite).
Pelitic	Quartz, Albite, Muscovite, Chlorite (Epidote, Chloritoid).	Quartz, Muscovite, Chlorite (Albite, Epidote, Chloritoid, Biotite).	Quartz, Muscovite, Almandine, Oligoclase-Andesine (Biotite, Kyanite, Staurotite).	Quartz, Muscovite, Oligoclase-Andesine, Biotite, Al_2SiO_5 (Almandine).
Quartzo-Feldspathic	Quartz, Albite, Muscovite (Epidote).	Quartz, Albite, Microcline (Muscovite, Epidote, Biotite).	Quartz, Oligoclase-Andesine, Microcline, Muscovite (Epidote, Biotite).	Quartz, Oligoclase, Andesine, Microcline, Biotite, Al_2SiO_5.
Temp. range Press. range	400 - 450 °C 2 - 5 kbars.	450 - 500°C 3 - 7 kbars.	500 - 550°C 4 - 8 kbars.	550 - 625°C 4 - 10 kbars.

* Basic assemblages may be of igneous or sedimentary origin.

(Compilation after Fyfe et. al., 1958; Miyashiro, 1968; Hyndman, 1972).

(10%) and epidote (2%). Milligan (1970) and Chatterjee (1979, personal communication) reported finding amphibolites containing hornblende several metres to the north, at the mouth of Second Gold Brook. Within the slates and feldspathic quartzite, euhedral crystals of chlorite occur as alteration products of garnet. Garnet is only partially replaced in some samples (SD-48) and found unaltered in the vicinity of the intrusive (SD-61, SD-62). This is indicative of retrograde metamorphism.

Amphibolites containing blue-green hornblende and chlorite, have been found on Middle River. These have plagioclase with oligocene-andesine compositions, and are therefore placed in the lower amphibolite facies.

Amphibolitic rocks from Falls Brook show a typical middle amphibolite facies assemblage. They contain green hornblende, plagioclase (oligocene-andesine), biotite and no chlorite. Almandine is found in one sample where the partitioning of magnesium and iron indicate a metamorphic temperature of approximately 550°C. This is the boundary of the lower and middle amphibolite facies.

The gneiss in contact with a pod of granite at the head of Falls Brook, has a granitic composition, and is probably of middle amphibolite grade metamorphism. This granitic gneiss is the characteristic rock type for several kilometres to the north of the granite pod (Milligan, 1970). Its medium-grained granitic texture reflects a high degree of recrystallization. The granite, which is in contact with the gneiss, shows no mineralogical evidence of metamorphism, but grains do show undulose extinction, bending and fracturing.

In general, a gradational metamorphic sequence is observed, from upper greenschist in the south to middle amphibolite in the north.

Since only one section was mapped, it is not possible to estimate the strike of these metamorophic zones from these data alone.

The area of the mine site in Second Gold Brook shows an anomalous middle greenschist grade. As noted in this report, the grade up-section and down-section from this zone is upper greenschist. Milligan (1970) and Chatterjee (1979, pers. comm.) have also reported higher grades (upper greenschist to amphibolite) to the northeast, along the strike of these same units. It is therefore believed that the grade of metamorphism observed in the vicinity of the old mine site is anomalously low, and caused by factors other than just the regional metamorphism.

2. Processes of Metamorphism

Three different types and stages of metamorphism are thought to have produced the present suite in the Gold Brooks section. They are:

1. regional metamorphism
2. contact metamorphism associated with granitic intrusion
3. metasomatism associated with emplacement of mineralized quartz veins.

Whereas the metasomatic alteration is believed to occur last, the relative timing of the first two events is uncertain.

Therefore two possibilites present themselves. Either regionally metamorphed rocks were intruded by granitic bodies, or, the regional metamorphism followed the intrusive period (It may also be possible that these events are contemporaneous.)

Intrusive rocks in the section are Cambrian in age (Cormier, 1972). Intrusion of granitic magmas would presumably have caused contact metamorphism on a variable scale dependent upon the size of the intrusive body. No contact metamorphism is recognizable adjacent to the pluton at the head of Second Gold Brook, but neither is the contact itself visible. No contact metamorphism is visible associated with the pod of granite at the head of Falls Brook, where the contact is clearly visible.

Intrusive rocks, particularly granites, are commonly related to major orogenies and usually occur 20-40 million years after the deformational event. So, granitic intrusion commonly follows regional metamorphism, though may not necessarily accompany it.

Granites of early Cambrian age may have been produced by the Avalonian orogeny during the Hadrynian. The George River Group must then be Hadrynian or possibly Helikian in age.

Weibe (1972, 1973) and Weeks (1954) believe that structural relations proven in northern Cape Breton Island are applicable elsewhere and that therefore, "the George River Group is probably Helikian in age and was deformed, metamorphosed and intruded prior to the accumulation of the Hadrynian Forchu Group" (Weibe, 1972).

Milligan (1970) and Helmstaedt et. al. (1973) believe the George River Group to be contemporaneous with the Forchu volcanics and that they are both Hadrynian in age.

It is generally agreed that the metamorphism leading to the present schists and gneisses of the George River Group was Paleozoic, and associated with the Acadian orogeny (Poole et. al.,1972; Weibe, 1972; Helmstaedt et. al., 1973). This has obliterated all traces of an earlier orogeny.

The almandine-biotite geothermometer indicates a metamorphic temperature of approximately 550°C. Assuming a normal geothermal gradient of 20 to 25°C/km and a crustal density of 2.6gm/cm^3, these rocks were buried to a depth of 22 to 27km and subjected to between 5.5 and 7 kilobars pressure. (Miyashiro, 1973).

The third and final metamorphic process is a metasomatic event. Gold-bearing quartz veins at the mine site on Second Gold Brook have produced an alteration in the wall rock which extends about 5 cm. from the vein. This argillic alteration is characterized by sericite, chloritized biotite and paragonite (Chatterjee, in Milligan, 1970). This assemblage is similar to that of the slates which are the host rocks containing these quartz veins.

It is possible that the low metamorphic grade which is exhibited by the slates and feldspathic quartzites may be related to the quartz veins. The fracturing which eventually leads to the formation of veins was accompanied by shearing. Solutions which precipitated the quartz veins may have also passed through these surrounding rocks. This could have produced the retrograde metamorhpism which is observed.

(b) Structure

Milligan (1970) has proposed that a large scale, low angle thrust fault may be present in the Middle River - Crowdis Mountain region, where the study area is located.

An overthrust occurs on Christopher McLeod Brook, approximately sixteen km to the east. Displacement is to the ENE on a scale of several kilometres. It is then possible that the same fault has affected the Middle River - Crowdis Mountain area.

The presence of such an overthrust in the region could explain the outcrop pattern of Carboniferous rocks in the area as well as the anomalous metamorphic grade in Second Gold Brook (ie. middle greenschist in the proximity of intrusives) (Milligan, 1970). At Gabbro Hill (see Figure 8), Cambrian intrusives, and Precambrian metasediments and volcanics are in contact with Horton conglomerates which are overturned to the west. George River Group rocks are also in contact with Windsor evaporites along a section to the south of Gabbro Hill. Horton and basal Windsor sediments have not been observed along the contact (Jones and Covert, 1972).

Minor faults with only small displacement are seen along the length of the Gold Brooks section.

Figure 8. Geology of Gabbro Hill Area. Outcrop of George River Group atop Gabbro Hill may be evidence of onverthrusting. Note George River outcrop atop Grabbo Hill.

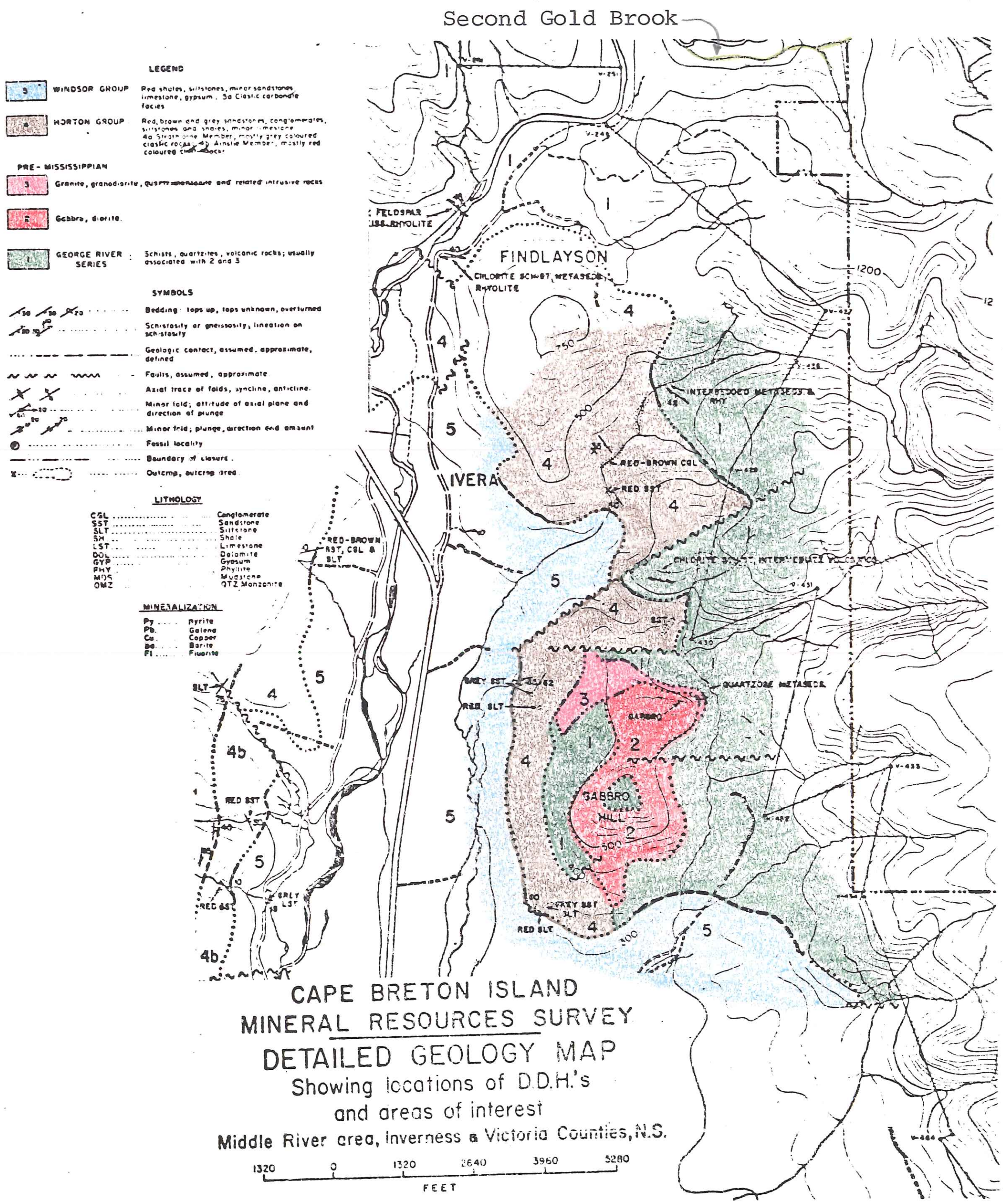
Second Gold Brook
LEGEND
WINDSOR GROUP
HORTON GROUP
PRE-MISSISSIPPIAN
Gabbro, diorite.
GEORGE RIVER SERIES
SYMBOLS
LITHOLOGY
MINERALIZATION
FELDSPAR
FINDLAYSON
RED-BROWN CGL
RED SST
INTERBEDDED METASEDS &
CHLORITE SCHIST, INTERMEDIATE VOLCANICS
QUARTZOSE METASEDS
GABBRO
GABBRO HILL
RED SLT
RED SST
4b
CAPE BRETON ISLAND
MINERAL RESOURCES SURVEY
DETAILED GEOLOGY MAP
Showing locations of D.D.H.'s
and areas of interest
Middle River area, Inverness & Victoria Counties, N.S.
1320 0 1320 2640 3960 5280
FEET

Figure 8.

To explain several anomalous geologic aspects Milligan (1970) has proposed that a thrust fault of George River Group, may outcrop in the study area at Gold Brooks. It was thought that such a feature would explain the anomalously low metamorphic grade in the vicinity of the mine in Second Gold Brook. It was thought that the alaskite at the head of the stream and at a shallow depth of 52 metres near the bottom of the brook (Mareast Explorations drill hole - reported by Milligan 1970), demanded a higher grade than what is observed.

It was hoped that an anomalous decrease in metamorphic grade in the area of the mine site could be linked to a thrust fault projected from evidence at Gabbro Hill and along the Carboniferous contact. A low-angle, large-scale thrust fault would not be unreasonable due to the presence of such a structure in Christopher MacLeod Brook.

A fault plane was originally proposed which had a strike of the Carboniferous - Precambrian contact along the west side of Crowdis Mountain. This plane would have to cut the top of Gabbro Hill so as to explain the 15 metre thickness of George River Group rocks found there. Horton and basal Windsor sections would then not be absent, but rather overlain by thrusted George River. The fault plane was also passed through the mine site on Second Gold Brook where the anomalous metamorphic grade occurs, as does evidence for a possible low-angle fault. The outcrop pattern for such a thrust is shown in Figure 9. The area to the east is the overthrust sheet.

Only in one location does this thrust contradict the observed geology. No George River Group has been recognized atop the 240 m.

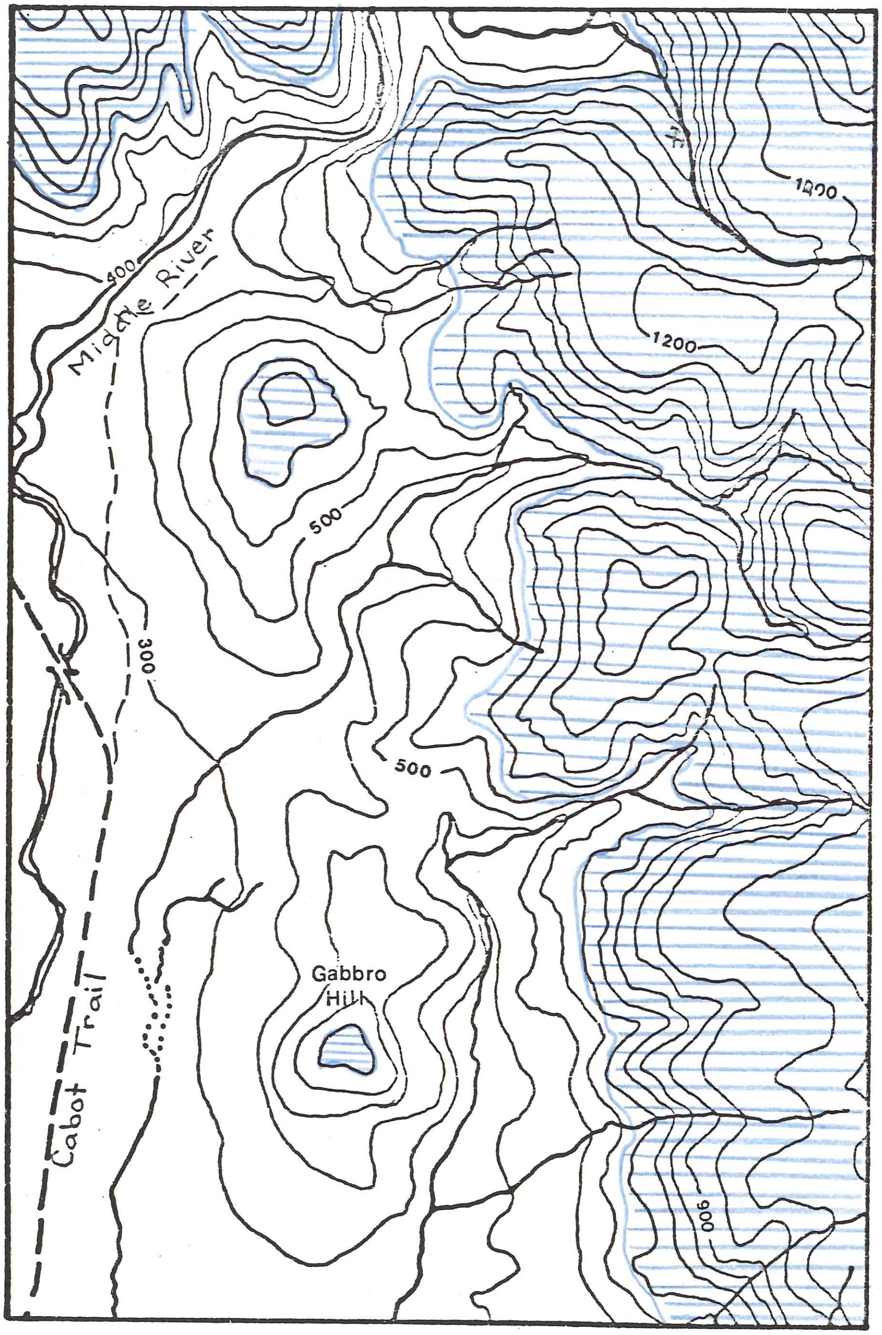

Figure 9: Model #1 Outcrop of thrusted sheet of George River Group rock in blue.

hill to the north of Gabbro Hill. Otherwise this model fits the Carboniferous - Precambrian contact along the Middle River Valley, nowhere positioning George River Group rocks where Carboniferous sediments have been observed.

The situation in Second Gold Brook could more probably be explained as a window through a thrusted sheet which exposed an area of lower metamorphic grade. This might also explain why the conglomerate band found in Second Gold Brook does not occur in brooks to the east or west. No structural evidence supports this hypothesis, though it could be related to brecciation observed in the margin of the alaskite body (Figure 10).

No evidence has been found to support the theory of a thrust fault outcropping in the Gold Brooks section. This therefore should be taken as negative evidence of such a structure being present in this area.

(c) Proto-lithologies

Feldspathic quartzites in the section contain what are believed to be original detrital grains of plagioclase; otherwise the mineralogy is dominantly recrystallized quartz and feldspar. No appreciable degree of metasomatism has been observed, so it is thought that the original rock must have been an arkose. The metamorphic grade (mid to upper greenschist) was not extreme enough to totally recrystallize the rock and so what were presumably larger grains of feldspar still remain. The remainder of the original sediment must have been finer

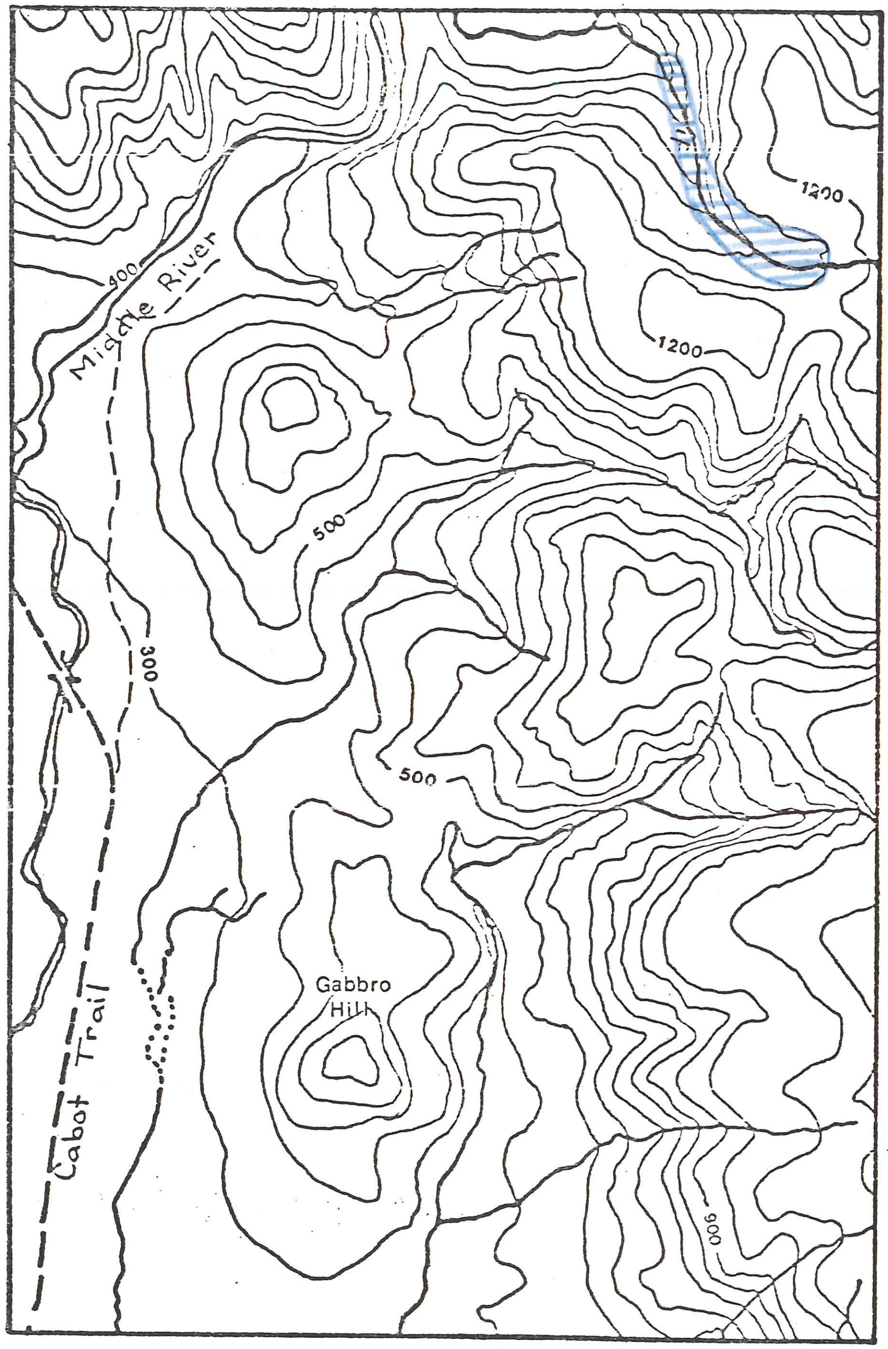

Figure 10: Model #2 Outcrop of window (in blue) through thrusted George River Group Rocks. Not projected into other areas of outcrop.

grained.

Variations in the sedimentary sequence are shown by bands of slightly different mineralogy. SD-49 is from the band rich in epidote and most likely involved the mixture of some carbonate in with the arkosic sediments. It may also be possible that a volcanic source was involved.

Figure 11 shows the fields of various rock types plotted on an ACF ternary diagram. If no input or loss of the plotted components has taken place, then a metamorphic rock should plot in the same position as its protolith.

Slates in the section, which contain large amounts of muscovite, chlorite and quartz, and have high alumina contents were originally shales derived from mudstones and siltstones.

Quartzites which occur interbedded with, and between, these units were originally sandstones, and because of the rather simple mineralogy of the quartzites, they must have been very clean sands.

The conglomerate unit still retains its original texture. Its matrix appears to have been a medium to fine grained sandstone; probably gradational from the slates since the conglomerate contains enough alumina to produce chloritoid and muscovite when metamorphosed.

The units in Second Gold Brook all appear to be of sedimentary origin. The sequence indicates deposition of a medium - to coarse - grained arkose which is interbedded with a finer, more siliceous, sand-

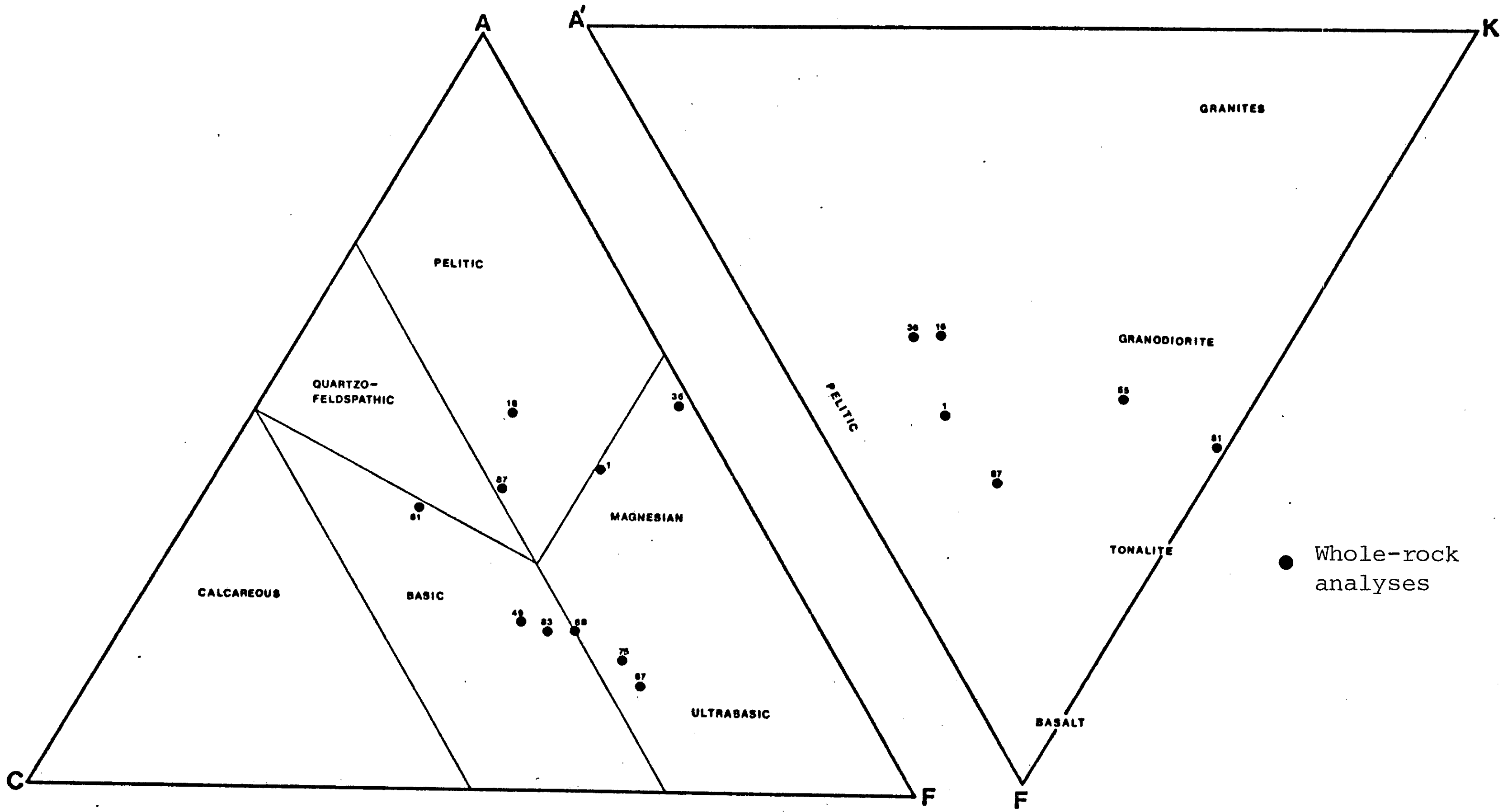

Figure 11: ACF and A'KF plots of whole-rock compositions. Fields indicate compositions of various rock types.

stone. Continued reduction in grain size on a smaller scale gradually passes into fine grained sandstones and shales. Cobble-sized fragments are then seen to have been deposited for a period of time in a fine matrix of predominantly sandstone. This is again followed by deposition of shales. The epidote-rich band in the feldspathic quartzites and the tremolite band in the slates are indicative of contamination from either a volcanic or carbonate source.

The origin of the amphibolite unit is not as simple. Amphibolites may be derived from mafic igneous rocks or from calcareous or calc-magnesian sediments. This range may also be subdivided, as amphibolites from mafic sources can be produced from lavas, dykes or tuffs. (Miyashiro, 1968).

Amphibolites in Falls Brook are interbedded with quartzites and minor slates which are believed to be of sedimentary origin since no reasonable igneous or metasomatic origin can be envisioned. Samples of amphibolite plot in the basic to ultrabasic field of Figure 11, and therefore do not appear to be the result of metamorphism of simple calcareous sediments. Massive calcite was found in association with amphibolite (SD-10). If the amphibolites were originally calcareous, this too should now be amphibolite.

The geometry of the amphibolite bands must reflect on their origin. The thinnly bedded units which appear very persistent along strike are definitely not dykes or flows, because they are too thin by comparison to the area they cover and are always stratiform.

Such environments as would have to be envisioned to explain this type of interbedding of calcareous sediments and sandstones, rule out a sedimentary origin for the amphibolite.

It is necessary then to postulate that the amphibolites are metamorphic derivatives of mafic tuffs. Engel et al. (1962) state that "thin persistant layers of tuff - with the composition of basalts - are very rare in, if not absent from least metamorphosed rock sequences of metasedimentary rock types." This suite would argue otherwise.

Within the amphibolitic unit, thicker (up to 20 m.) bands of 'quartzite' are believed to represent uninterrupted deposition of arkose. Thicker bands of amphibolite may be basaltic or andesitic lavas. Milligan (1970) reports pillowed structures in one exposure in Fourth Gold Brook, one and a half kilometres to the east along strike from this unit.

Analyses of five amphibolite samples and the hornblende in them show a very small field of compositions which indicates very little change in the source material and during transport and depositon.

Variations in the texture of the amphibolites is thought to depend on the thickness of the amphibolite band and the position within it. Thin bands are seen to exhibit better foliation and more fine elongate grains, while the thicker units tend to be more massive especially toward the centre and are coarser grained.

The original sequence which best appears to fit that observed in the amphibolite unit is deposition of arkosic sediments and minor shales which was repeatedly interrupted by episodes of mafic tuff deposition and occasionally a lava flow. The amphibolite compositions closely resemble andesites.

Chapter 6 Conclusions and Implications

Investigation of a section of amphibolites, feldspathic quartzite, slates and quartzites belonging to the George River Group at Gold Brooks has shown:

1. The section exhibits gradational regional metamorphism from upper greenschist in the SSE. to middle amphibolite in the NNW. No contact metamorphism was observed.
2. Investigation of a garnet-biotite geothermometer indicates a metamorphic temperature of approximately 550°C for the amphibolite facies rocks.
3. The original lithologies present in the section before metamorphism are believed to have been sandstones, arkosic sandstones, shales and a band of conglomerate. During deposition this sequence was repeatedly interrupted by mafic ash falls and lava flows.
4. The granitic bodies intruding the section have been post-dated by regional metamorphism which was followed by small-scale mineralization associated with quartz veins.
5. No evidence has been found to support the existence of any major thrust activity in this section.
6. No satisfactory explanation has been found for the anomalously low, possibly retrograde, middle greenschist metamorphic grade in Second Gold Brook.

The regional metamorphic grade has been shown to increase to the NNW in this section, though due to the linearity of the section, the strike of the metamorphic facies boundaries cannot be determined by this data alone. This work does,however,support work by Milligan (1970) where he indicates that the metamorphic grade appears to increase to the north.

Interpretation of the proto-lithologies proposed in this thesis may indicate facies changes within an offshore environment which were contemporaneous to nearby volcanic activity. Helmstaedt et. al. (1973), Wiebe, (1973), Bird et. al. (1970) and Poole et. al. (1972) propose the existence of an island arc in the position of Cape Breton during late Hadrynian - Cambrian times. This section may therefore be interpreted as back-arc sedimentation with recurrent volcanic episodes.

Further work to be done should include explanation of the metamorphic grade in central Second Gold Brook. Perhaps a thermal event associated with the quartz veins has induced retrograde metamorphism. Further geothermometry and age dating in that area may prove worthwhile.

A study of the correlation of amphibolites in the George River Group and volcanic of the Forchu and Bourinot Groups may yield more information about the relative ages of these rocks.

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Appendix A Detailed Petrology

This section describes in detail the rocks originally described in Chapter 3.

(a) Unit Description

A.1. Conglomerate

The conglomerate contains pebbles which are almost always quartz, only very few contain any feldspar. The matrix, which exhibits a good foliation, is 98% granoblastic quartz, with minor muscovite and hematite. Poorly developed laths of chloritoid occur as prophyroblasts (1-2mm) and show no preferred orientation. (slide description SD-20) (Photo 14).

A.2. Feldspathic Quartzite

Feldspathic quartzites are massive or banded and show a fine foliation. The dominant texture is granoblastic quartz (50-80%) with relict grains of plagioclase. Orthoclase, fine muscovite, and iron-rich chlorite are disseminated in the matrix. Lenticular albite relicts show complex twinning and partial polygonization (Photo 15). These have been identified as relict grains due to their often angular shape, though they always show rounded boundaries. Albite relict grains become more strained and poikiloblastic southward in this unit (SD-42 - SD-46) (slide description SD-43).

A band of epidote-rich meta-arkose (SD-47 - SD-49) contains up to 5% calcite. The epidote, as much as 40%, occurs in patches, appear-

Photograph 14. Conglomerate matrix, chloritoid laths in fine quartz groundmass; SD-20, PPL, x16.

Photograph 15. Relict plagioclase in feldspathic quartzite; SD-43, XN, x20.

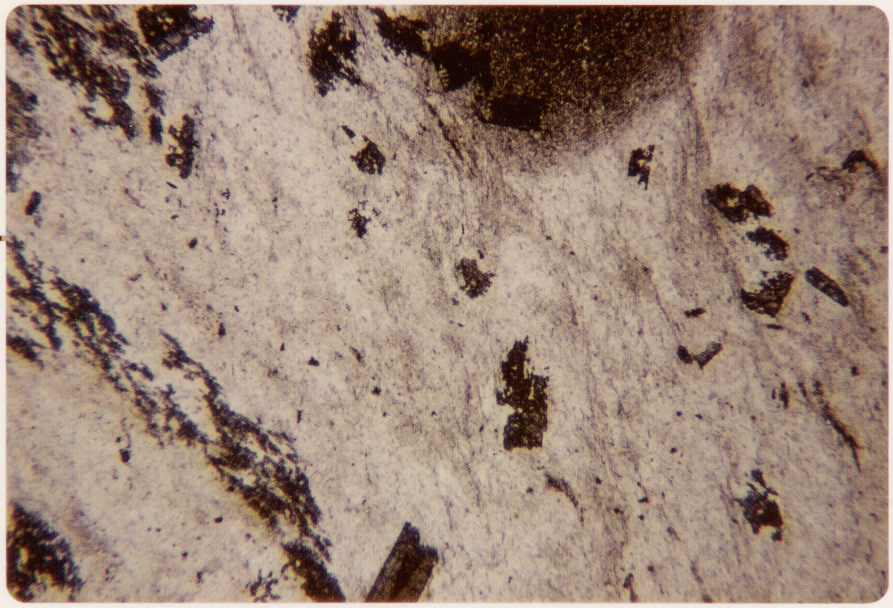

PHOTO 14

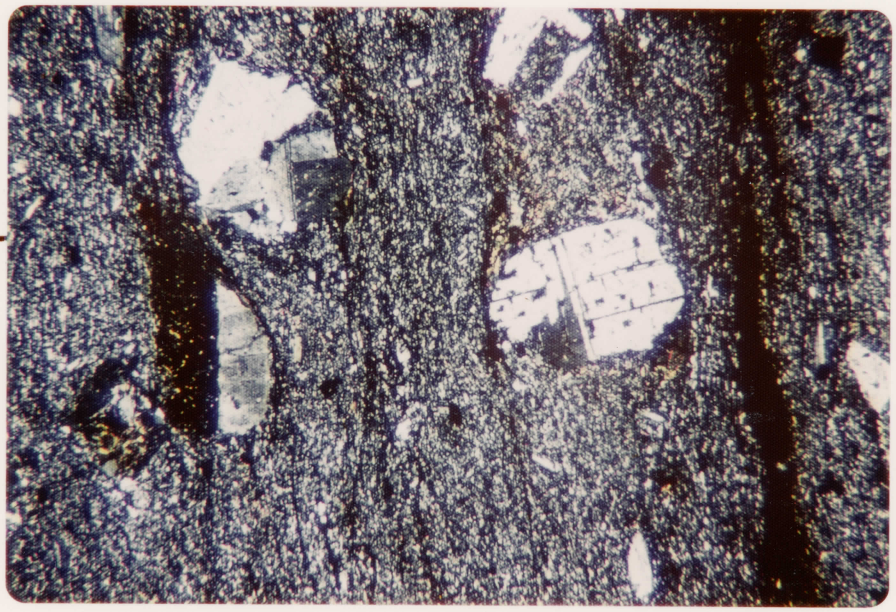

PHOTO 15

ing to totally replace some phase which is no longer present. Epidote is seen elsewhere associated with albite (Photo 16) as a replacement of plagioclase. (slide description SD-49).

Some of the feldspathic quartzites are iron-rich and contain abundant hematite and magnetite (SD-53 - SD-57). These also usually contain strained albite grains and show a good foliation due to fine layers of iron-rich micas and chlorite. (slide description SD-54).

Near the alaskite (within 15m), small almandine crystals with sieve texture are developed in slightly coarser grained (0.05 - 0.2mm) feldspathic quartzites. (SD-61). Euhedral grains of magnetite are rimmed by hematite. Chlorite is observed as pseudomorphs of garnet throughout this unit.

A.3. Slate

The slates can be more correctly described as chlorite - muscovite schists produced from pelitic sediments. These rocks are extremely fine grained, the matrix consisting of grains typically < 0.02 mm. It is characteristically 30-40% quartz, 5-10% feldspar, 40-50% muscovite, sericite and chlorite, with minor biotite and magnetite.

Within the matrix, ragged laths and lenticles of chlorite (0.4-0.8mm) are more or less aligned with the general foliation. Euhedral hexagons of chlorite (0.1mm) are also developed.

Chloritoid (2mm) is developed as syn-tectonic porphyroblasts in SD-23 while seive textured almandine occurs 5m. away in SD-24 and SD-25

Photograph 16. Relict grains of plagioclase being replaced by epidote in feldspathic quartzite; SD-60, XN, x20.

Photograph 17. Chlorite schist, chloritoid lath growing oblique to foliation; SD-23, PPL, x50.

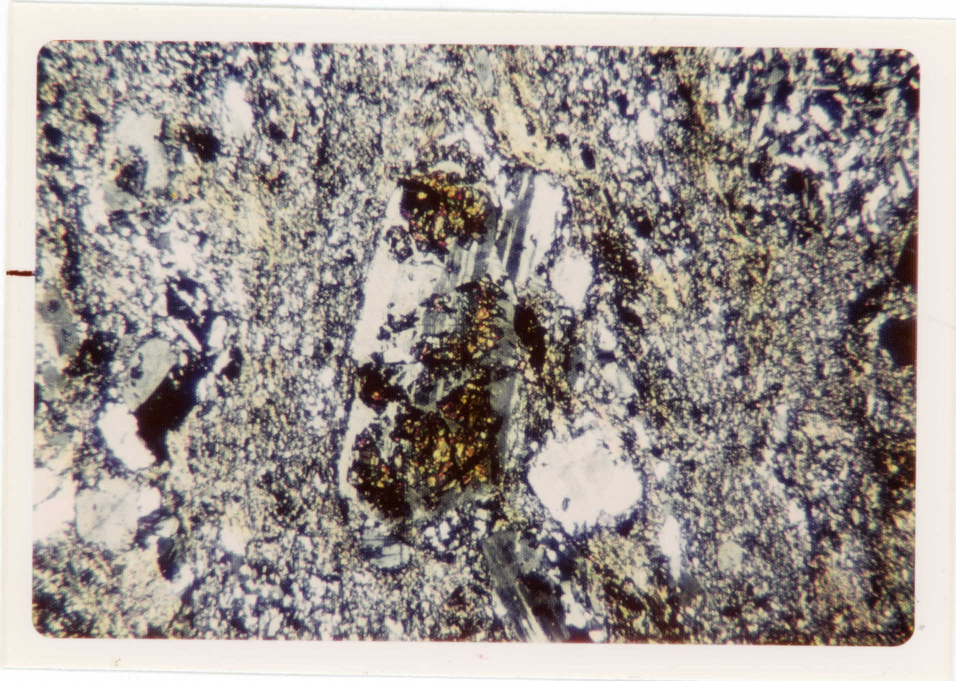

PHOTO 16

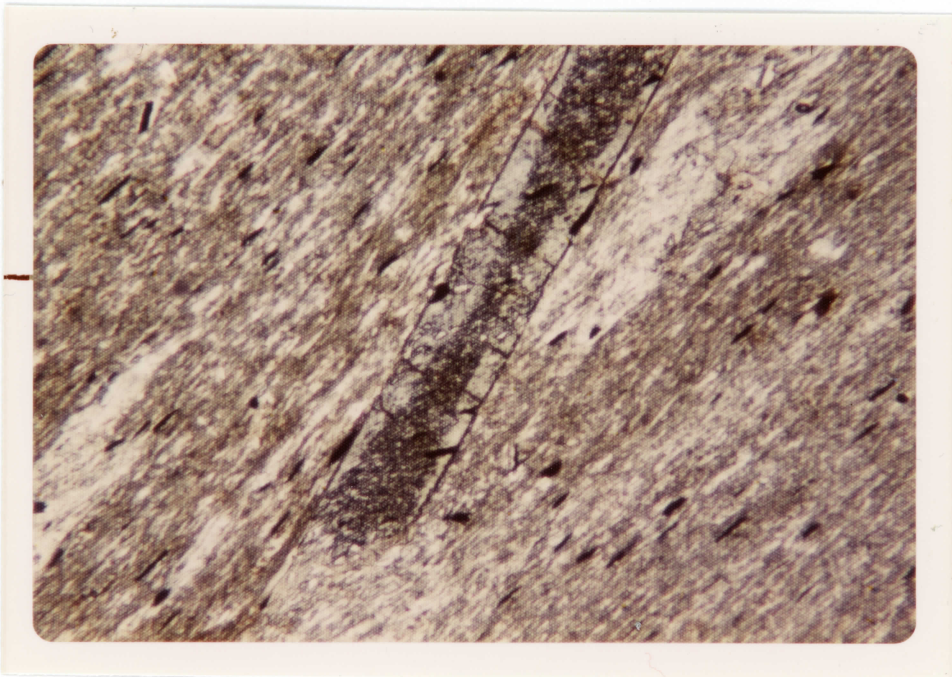

PHOTO 17

and along Middle River. (slide descriptions SD- 19, SD-67) (Photos 19, 20).

Calcite is found in some samples as either veinlets or disseminated grains, comprising < 5% of the rock. Massive carbonate has been found in only one sample SD-10 (Photo 21), where it is in direct contact with amphibolite.

Almandine garnet has been found in one sample, SD-14B, along with biotite and hornblende. (slide description SD-14B).

The quartzites are interbanded with the amphibolites and grade into them due to the disappearance of hornblende, biotite and ilmenite. The amphibolites contain up to 70% hornblende; anything in this unit with less than 10% amphibolite is termed a quartzite. Quartzites may also contain muscovite calcite and hematite in minor amounts. The plagioclase present is always albite. (slide descriptions SD-81, SD-71).

B.1. Alaskite

The alaskite on Second Gold Brook was sampled only on what is now seen as a marginal phase. This rhyolitic phase is fine grained, banded (flow banding ?) and shows minor brecciation. SD-62 contains dominantly quartz with albitic plagioclase and orthoclase. Minor chlorite, sericite and hematite are also present. Rounded elongate grains (0.5-2.0mm) have been fragmented after replacement by fine, highly altered minerals of unknown composition. (slide description SD-62).

(Photo 17).

Non-ferrian zoisite occurs with hematite in SD-35 which also contains porphyroblasts of tremolite-actinolite (slide description SD-35) (Photo 18).

The strong foliation-schistosity is produced by fine needle-like minerals in the matrix (chlorite and muscovite) and elongate porphyroblasts. Chlorite exists as primary crystals and as fine grained pseudomorphs of garnet throughout the unit.

A.4. Quartzite

Quartzites are interbedded with, and act as, gradational units between the slates and feldspathic quartzites. Generally, they consist almost entirely of quartz (50-60%) and plagioclase (20-30%), biotite and chlorite being absent or in minor amounts. The oxide phase is magnetite which occurs in a fine grained mass of granoblastic quartz and albite. Alteration products present usually include hematite sericite and sometimes graphite.

A.5. Amphibolites

The amphibolites are comprised of tschermakitic hornblende, plagioclase (oligocene-andesine), quartz and biotite or chlorite. The oxide phase is always ilmenite. Very minor pyrite may be present. (slide descriptions SD-68 , SD-75).

The amphibolites are unaltered except in lower Second Gold Brook

Photograph 18. Zoisite (blue) with hematite in tremolite-actinolite schist; SD-35, XN, x200.

Photograph 19. Epidote and calcite in chlorite schist; SD-19, XN, x20.

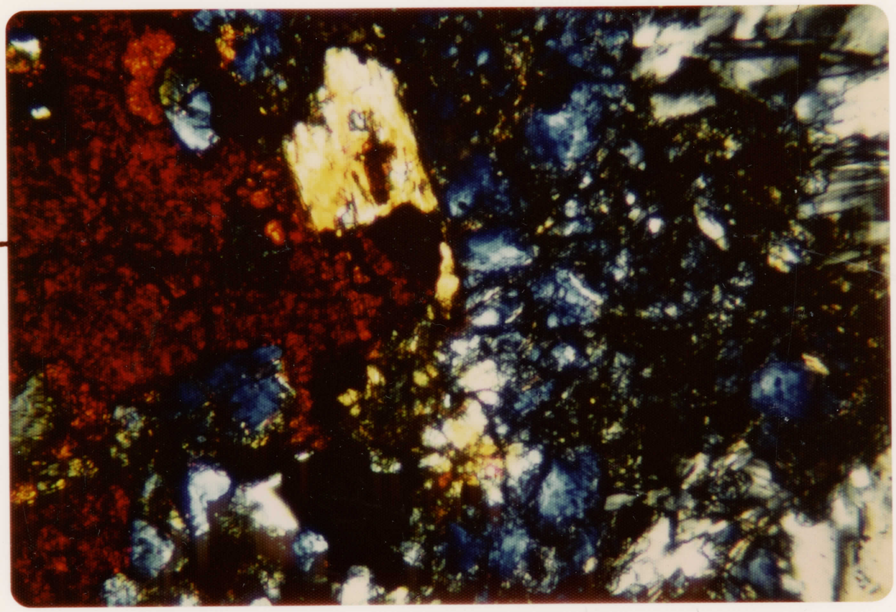

PHOTO 18

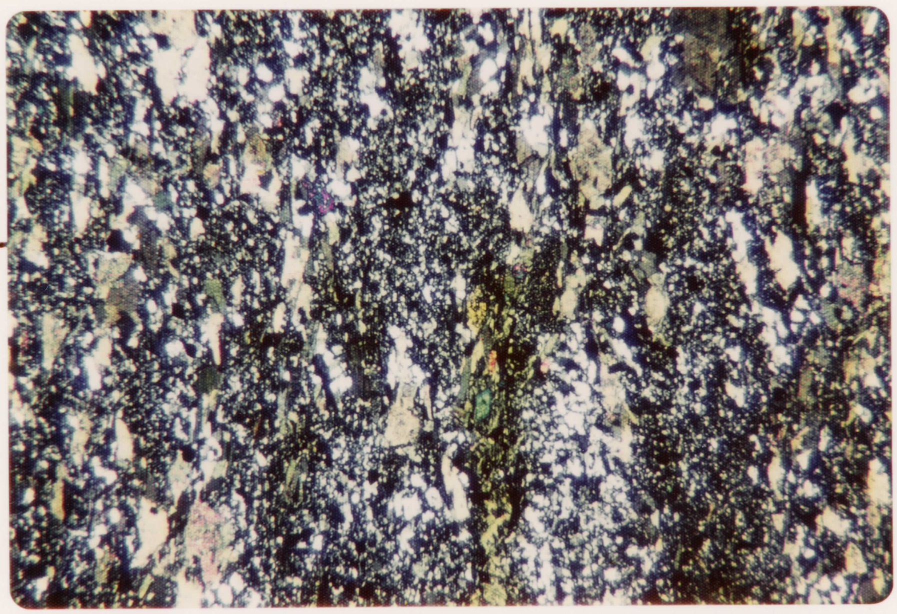

PHOTO 19

Photograph 20. Amphibolite with blue-green tschermakitic hornblende; SD-67, PPL, x125.

Photograph 21. Amphibolite interbedded with massive calcite; SD- 10, XN, x12.

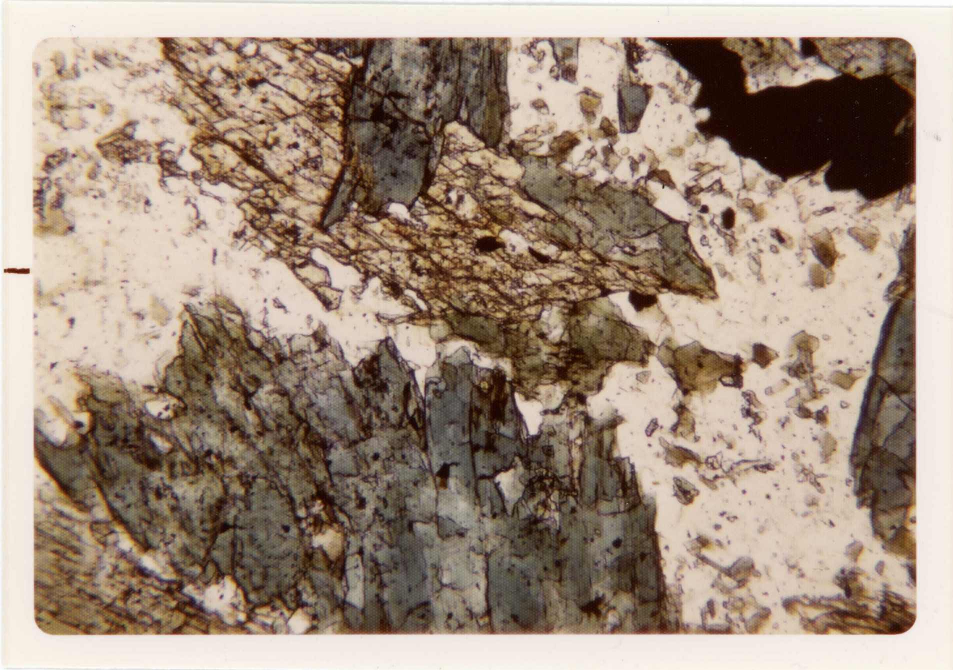

PHOTO 20

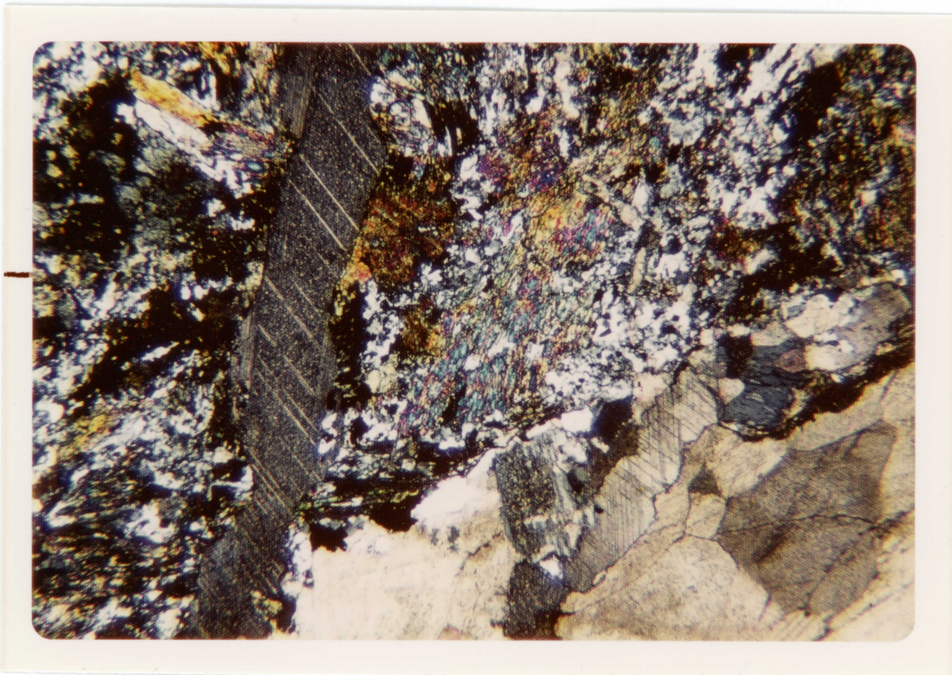

PHOTO 21

B.2. Granite

The granite on Falls Brook is coarse grained and contains $< 1\%$ opaques. It is approximately 50% plagioclase 35% quartz, 15% orthoclase, with minor muscovite and garnet. Quartz grains often show intricate interlocking textures. All grains show undulose extinction (slide description SD-89) (Photo 22).

Photograph 22. Granite, intricate interlocking quartz grains;

SD-89, XN, x30.

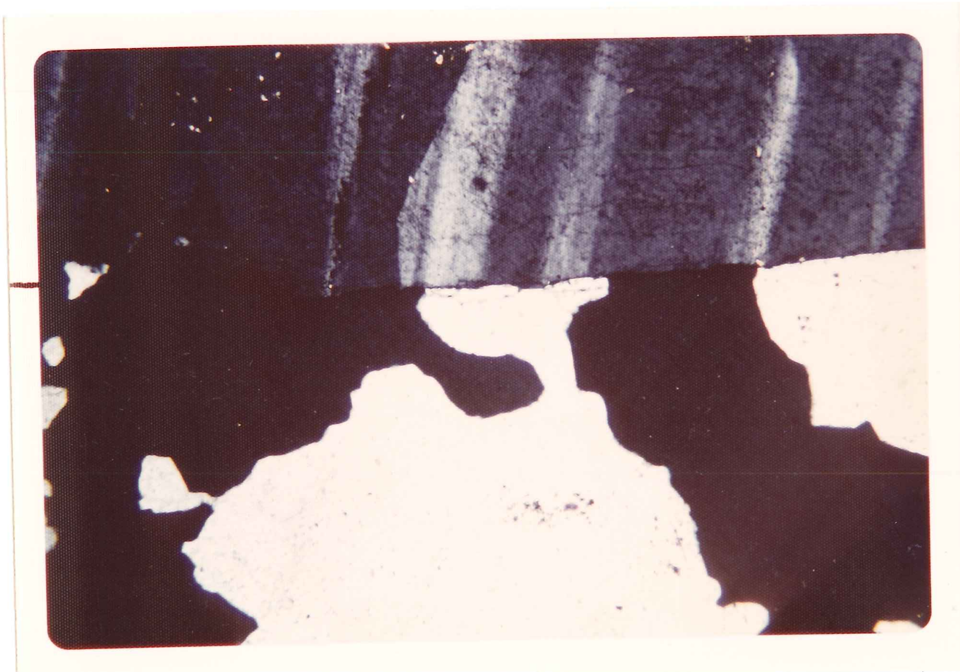

PHOTO 22

Slide # SD-14B Location: Falls Brook GRADE: Middle Amphibolite

Garnet-Bearing Hornblende Amphibolite

Mineral	%	Description
Hornblende	50%	Euhedral to subhedral crystals, 0.5-3.0mm, Elongate Poikiloblastic, green to blue-green.
Biotite	10%	Elongate grains, 0.2-0.5mm, unaltered, often bent, split or kinked.
Almandine	2%	Light pink, euhedral, 1.5mm, elongate in direction of schistocity, fractured, poikiloblastic.
Ilmenite	5%	Irregular grains, 0.05-0.1mm, contained in all other phases.
Quartz	25%	Granoblastic polygonal, 0.02-0.05mm.
Plagioclase	5%	Granoblastic polygonal, 0.05-0.10mm.
Calcite	1%	Occurs in fractures, long thin grains.
Chlorite	3-4%	Very fine grained, assoc. with fractures minor amounts in groundmass.

Textures and Alteration

TEXTURES: Good foliation primarily euhedral grains

ALTERATION: Very clean
Alteration closely associated with fractures in rock.

Slide # SD-19 Location: Second Gold Brook GRADE: Upper Greenschist

Calcite-rich chlorite schist

Mineral	%	Description
Quartz	35%	Granoblastic, < 0.02m.
Calcite	25%	Elongate aggregates of grains, 0.2-0.8mm., occur as bands, poikilitic.
Chlorite	15%	Fine grained crystals alteration on biotite.
Biotite	10%	Ragged elongate grains, 0.2-0.6mm., predominantly well foliated.
Plagioclase	5%	Rounded grains, 0.05-0.2mm., poor twinning.
Magnetite	3%	Euhedral to subhedral grains, 0.02-0.10mm.
Epidote	2%	Euhedral to subhedral, prismatic, 0.1-0.7mm.

Textures and Alteration

Good schistosity reflected by alignment of epidote, biotite and chlorite. Microscopic banding produced by separation of biotite, chlorite and calcite from quartz and plagioclase. Minor chloritization of biotite.

Slide # SD-20 Location: Second Gold Brook GRADE: Greenschist

Conglomerate Matrix

Mineral	%	Description
Quartz	90%	Granoblastic interlocking texture.
Muscovite	3-4%	Fine grains interspersed with quartz, tends to form patches.
Chloritoid	5-8%	Ragged laths, 0.5-1.5mm., no prefered orientation, inclusions of quartz.
Hematite	4%	Very fine grained.

Textures and Alteration

TEXTURES: One good foliation visible.
Chloritoid is post-tectonic

ALTERATION: Chloritoid altering to muscovite and quartz.

Slide # SD-35 **Location:** Second Gold Brook GRADE: Greenschist

Amphibolitic feldspathic quartzite

Mineral	%	Description
Quartz Orthoclase	35%	Very fine grained granoblastic.
Plagioclase	15%	Rounded poikilitic relict grains, 0.5-1.5mm. undulose extinction, twinning poor to absent. Also as fine grains in groundmass.
Tremolite-Actinolite	35%	Fractured porphyroblasts, 1-2mm, anhedral. Also as fine grained in groundmass.
Hematite	2-3%	Associated with and as alteration of magnetite large irregular grains, 2mm with quartz inclusions.
Magnetite	5%	Anhedral, 0.05-0.25mm, altering to hematite.
Calcite	5-8%	Anhedral grains, 0.3-0.5mm.
Zoisite	3-4%	Irregular grains, 0.1-0.3mm., usually in patches deep blue birefringence.

Textures and Alteration

TEXTURES: No distinct foliation, minor fracturing of relict feldspars

ALTERATION: Minor sericitization of feldspar.
Magnetite replaced by hematite.

Slide # SD-36 **Location:** Second Gold Brook **GRADE:** Greenschist

Highly altered meta-pelite

Mineral	%	Description
Quartz	35%	fine grained in matrix
Plagioclase	30%	fine grained in matrix
Chlorite	25%	extensive fine chlorite-througout groundmass
Magnetite	5%	very eroded euhedral grains, rimmed with hematite or void.
Biotite	3%	platy, 0.2-0.4 mm.
Muscovite	1-2%	fine grained in matrix

Textures and Alteration

Extensive alteration, appears due to metasomatic/hydrothermal event which created chlorite and muscovite while destroying magnetite phase.

Slide # SD-43 Location: Second Gold Brook GRADE: Greenschist

Typical feldspathic quartzite

Mineral	%	Description
Quartz Orthoclase	} 70%	Very fine grained matrix.
Plagioclase	20%	Occurs as fine grains in matrix and rounded relict grains, 0.5-2.0mm., either massive or multigrained inclusions, twinned.
Epidote	2%	Very fine grained, anhedral
Muscovite	5%	Fine grained disseminated throughout matrix and in pressure shadows of porphyroblasts.
Magnetite	2%	Euhedral to subhedral, 0.01-0.03mm., minor associated hematite.
Chlorite	2-3%	Platey or fine-grained, dispersed throughout matrix, associated with muscovite prismatic grains, 0.05-0.1mm. Replaces garnet.

Textures and Alteration

TEXTURES: Good foliation wraps around porphyroblasts. Crenulated stringers of epidote indicate two deformations. Inclusions in Plagioclase reflect a planar structure.

ALTERATION: Chloritization of mica and epidote. Epidote appears to replace plagioclase.

Slide # SD-49 Location: Second Gold Brook GRADE: Greenschist

Epidote-rich meta-arkose

Mineral	%	Description
Epidote	40%	Anhedral grains, 0.1-0.5mm., fine grained masses possibly as pseudomorphs after plagioclase or hornblende.
Quartz	10%	Very fine grains in matrix.
Plagioclase	25%	Albitic, < 0.05mm. in matrix with quartz, good twinning also as twinned relicts, 0.5-1.5mm.
Chlorite	10%	Light green, massive to elongate crystals, usually micro-crystalline aglomerates.
Magnetite	3-4%	Euhedral to subhedral grains, < 0.05mm, disseminated throughout matrix.
Hematite	<1%	Very fine grains in matrix.
Sericite	<1%	Associated with feldspars.
Orthoclase	10%	Fine anhedral grains in matrix.

Textures and Alteration

TEXTURES: Moderate foliation, appears to wrap around crystal masses which replace relicts.

ALTERATION:
- Chlorite occurs as alteration of either epidote or the phase which epidote replaces.
- Sericite occurs as alteration of feldspars.

SD49 May be a low grade equivalent of the amphibolites, or a feldspathic quartzite which is anomalously rich in iron, calcium and magnesium. The presence of albite reflects the later, while the bulk composition is amphibolitic. No epidote is intimately associated with the plagioclase.

Slide # SD-54 **Location:** Second Gold Brook GRADE: Greenschist

Typical feldspathic quartzite

Mineral	%	Description
Quartz Orthoclase	60-65%	Elongate granoblastic to interlocking grains, 0.05-0.15mm. Also coarser (0.2-0.3mm) strained aggregates forming lenticular 'Augen'.
Plagioclase	10%	Rounded relicts, 0.3-0.7mm, with inclusions (ms. & qtz.) and carlsbad-albite twinning.
Magnetite	2%	Euhedral grains (0.1-0.5mm) rimmed by hematite.
Muscovite	10%	Fine grained, occurs in bands.
Chlorite	15%	Fine grained, Iron-rich, primarily occurs in bands with muscovite.

Textures and Alteration

TEXTURES: Very good foliation which is interupted by plagioclase relicts and multigranular lenticles of quartz. Foliation wraps around these.

ALTERATION: Chlorite may be replacing biotite
Magnetite almost entirely altered to hematite
Minor sericitization of plagioclase.

Slide # SD-55 **Location:** Second Gold Brook **GRADE:** Greenschist

Feldspathic Quartzite

Mineral	%	Description
Quartz	50%	fine grained in matrix
Plagioclase	35%	albite,rounded relict grains, 0.4-1.2 mm, also fine grained in matrix
Chlorite	10%	very fine grained in matrix, pseudomorphs after garnet
Muscovite	5%	fine grained in matrix
Magnetite	1-2%	euhedral, 0.05-0.2 mm, rimmed by hematite

Textures and Alteration

Hematite staining in cracks, extensive shearing, shadows developed around plagioclase grains.

Slide # SD-62 Location: Second Gold Brook GRADE: Upper Greenschist

Brecciated Rhyolite

Mineral	%	Description
Quartz	40%	Granoblastic to interlocking elongate grains, 0.02-0.10mm.
Feldspar	30%	Granoblastic to interlocking elongate grains, 0.02-0.30mm. Plagioclase is albitic and sometimes shows twinning, extensive sericitization.
Almandine	2%	Euhedral grains, 0.1-0.4mm., foliation wraps around garnet, fine inclusions mimic planar structure.
Epidote	10%	Fine grains in matrix.
Hematite	2%	Minor irregular grains, < 0.05mm.
Chlorite	20%	Very fine grained masses, iron-rich, throughout groundmass.

Textures and Alteration

TEXTURES: Rounded grains replaced by fine grained crystal masses. Then fractured during minor brecciation of rock. Banding (flow banding ?) wraps around larger grains.

ALTERATION: Extensive - development of chlorite and sericite throughout entire rock.

Slide # SD-67 Location: Middle River GRADE: Lower Amphibolite

Typical blue-green hornblende amphibolite

Mineral	%	Description
Hornblende	50%	Blue-green, 0.5-2mm, elongate, poikiloblastic
Ilmenite	5%	Irregular grains, 0.2-0.5mm.
Biotite	5%	Laths, < 0.3mm, often chloritized.
Hematite	<1%	Very fine grained, associated with ilmenite
Quartz	15%	Fine granoblastic matrix.
Plagioclase	25%	Subhedral laths to polygons, < 0.8mm. Good twinning andesine to oligoclase.
Chlorite	?	Very fine grained in matrix.

Textures and Alteration

TEXTURES: No foliation present - massive.

ALTERATION: Biotite altering to chlorite
Minor hematite alteration of hornblende

Slide # SD-68 Location: Falls Brook GRADE: Middle Amphibolite

Typical hornblende Amphibolite

Mineral	%	Description
Hornblende	60%	Very pale green, 1-2.5mm, and < 0.2mm, subhedral porphyroblasts and acicular grains.
Biotite	1-2%	< 0.4mm, elongate grains, usually found as aggregates, no alteration.
Ilmenite	4-5%	Irregular grains, 0.1-0.5mm.
Quartz	15%	Fine granoblastic matrix.
Plagioclase	20%	Anhedral grains < 0.3mm, andesine.
Calcite	4%	As discontinuous veinlet.

Textures and Alteration

TEXTURES: SYN-tectonic hornblende porphyroblasts in foliated groundmass. Foliation exhibited by biotite, acicular, hornblende, and slightly ovoid grains of quartz and plagioclase.

ALTERATION: Very clean
Very minor alteration in matrix-sericite?

Slide # SD-71 **Location:** Falls Brook GRADE: Middle Amphibolite

Typical "quartzite" from amphibolite unit

Mineral	%	Description
Quartz	65%	Polygonal to interlocking grains, 0.02-0.10mm.
Plagioclase	20%	Subpolygonal grains, 0.02-0.10mm and poikilitic relict grains, 1.5-3.0mm, which contain muscovite and sericite.
Ilmenite	3-5%	Irregular grains, 0.2-0.4mm, usually occur as aggregates.
Muscovite	3-5%	Ragged platy grains, 0.05-0.20mm.
Chlorite	3-5%	Fine grained, acicular, iron-rich, associated with ilmenite and minor hematite and calcite.
Calcite	< 1%	
Hematite	< 1%	

Textures and Alteration

TEXTURES: Good foliation.

ALTERATION: Chlorite may be replacement of biotite
Plagioclase altering to sericite and muscovite
Ilmenite sometimes rimmed by hematite.

Slide # SD-75 **Location:** Falls Brook GRADE: Middle Amphibolite

Typical hornblende amphibolite

Mineral	%	Description
Hornblende	60%	Elongate anhedral porphyroblasts 1-3mm, and acicular grains, < 0.4mm, blue-green, to pale yellowish brown in colour.
Biotite	2-4%	Acicular to elongate laths, anhedral, < 0.02mm, dark brown - strong pleochroism, often contained within hornblende.
Ilmenite	5-8%	Agglomerates and irregular grains, < 0.01mm.
Quartz	25%	Granoblastic polygonal, < 0.02mm.
Plagioclase	15%	Anhedral grains, < 0.02mm, intespersed in matrix with quartz, twinning often absent, andesine.

Textures and Alteration

TEXTURES: Porphyroblasts tend to be aligned with well foliated matrix.

ALTERATION: None

Slide # SD-81 **Location:** Falls Brook GRADE: Middle Amphibolite

Typical "Quartzite" from amphibolite unit.

Mineral	%	Description
Quartz	50%	Granoblastic, < 0.1mm.
Plagioclase	30%	Granoblastic < 0.1mm, albitic, usually untwinned. Minor porphyroblasts complex aggregates, 0.8-1.0mm.
Muscovite	6-7%	Tabular, irregular grains, often with inclusions, 0.1-0.4mm, also acicular < 0.05mm. and microcrystalline masses (sericite).
Calcite	3-4%	Irregular grains, < 0.2mm.
Hematite	1-2%	Indistinct fine grained masses.
Clay	4-6%	Dark brown, in crack between fragments.

Textures and Alteration

TEXTURES: Fine foliated quartzite, brecçiated (fragments 1-5mm) with matrix of clay, calcite, sericite and hematite. Rock is 10-15% matrix.

ALTERATIONS: Extensive within matrix - sericite and hematite.
Brecciation may have produced fine powder which has become the matrix.
Influx of iron appears necessary.

Slide # SD-83 **Location:** Falls Brook GRADE: Middle Amphibolite

Typical hornblende amphibolite in proximity of intrusion

Mineral	%	Description
Hornblende	60%	Green, elongate porphyroblasts, 0.3-3mm.
Biotite	5%	Dark brown, elongate to platey grains, 0.8-0.2mm.
Ilmenite	4-5%	Elongate, rounded grains, 0.02-0.1mm, not found as aggregate masses.
Quartz	20%	Granoblastic polygonal, < 0.2mm.
Plagioclase	10%	Granoblastic polygonal, < 0.2mm, twinning often absent. Andesine.

Textures and Alteration

TEXTURES: Good foliation exhibited by biotite, hornblende porphyroblasts show no preferred orientation.
Crenulation evident.

ALTERATION: Very minor alteration in matrix - sericite?
Calcite vein.

Slide # SD-89 Location: Falls Brook GRADE: Middle Amphibolite

Granite

Mineral	%	Description
Quartz	35%	Irregular grains, 1-3mm, Intericate mosaic intergrowths.
Plagioclase	50%	Irregular grains, 1-5mm, Intericate intergrowths bent, twinning; albite, carlsbad and pericline twinning. Undulose extinction.
Orthoclase	15%	Irregular grains, 0.5-2mm, undulose extinction.
Muscovite	< 1%	Subrounded grains, 0.05-0.1mm.
Garnet	< 1%	

Textures and Alteration

TEXTURES: Coarse grained, granoblastic

ALTERATIONS: None

Appendix B Laboratory Techniques

Chemical analyses were performed on a Cambridge Mark V Electron Microprobe with operating conditions of 15Kv EHT and 15 na probe current and an Ortec Energy Dispersive System. The software program is EDATA, developed by Smith and Gold at the University of Alberta.

Standards used in mineral analyses were as follows:

hornblende: Kaersutite, Manganese

garnet: Kaersutite, Jar Garnet

biotite: Kaersutite, Manganese, Biotite LP6

ilmenite: Kaersutite, Manganese

magnetite: Kaersutite, Manganese

plagioclase: Kaersutite, Manganese, Albite, Sanidine, An_{60}

These enable determination of major elements to an accuracy of $\pm$ 1.5-2.0% with a detection limit of 0.1% for most elements, 0.3% for sodium and 0.2% for magnesium. Analyses quoted are the average of five or more spot analyses.

Whole-rock analyses were determined by probing homogeneous glass beads formed by fusion in a vacuum on tantalum strips. Microprobe standards used in their analyses were Kaersutite, manganese and Sanidine. Precision and accuracy of this method was determined by comparison of analyses of U. S. G. S. standard BCR-1 with accepted values. (Table 6) Glass samples were rastered to ensure homogenity and compositions quoted are averages of three or more rasters.

Table 7. BCR-1 Standard Analyses.

OXIDE	GLASS BCR-1 OXIDE WT %	PRECISION (at 1 S.D.)	ACCURACY
SiO_2	54.50	± 1.1%	± 1.6%
TiO_2	2.61	± 4.6%	+ 16.5%
Al_2O_3	13.45	± 1.3%	- 2.8%
FeO	12.85	± 6.2%	+ 4.3%
MnO	0.10		
MgO	3.66	± 5.1%	+ 3.9%
CaO	7.28	± 2.5%	+ 3.6%
Na_2O	2.92	± 4.1%	- 13.7%
K_2O	1.68	± 6.0%	- 2.9%