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GEOLOGICAL AND GEOCHEMICAL INVESTIGATION OF PLUTONIC SUITES IN THE SISSON BROOK AREA YORK COUNTY, NEW BRUNSWICK

GEOLOGICAL AND GEOCHEMICAL INVESTIGATION OF PLUTONIC SUITES IN THE SISSON BROOK AREA YORK COUNTY, NEW BRUNSWICK

by

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A sequence of plutonic rocks in the Sisson Brook claims group owned by Kidd Creek Mines Ltd., range in composition from gabbro at the margin through diorite and quartz diorite to the Nashwaak Granite at the core. Field relations show the gabbros to be oldest, granites the youngest.

A regional foliation developed in the gabbro, diorite and to a lesser extent quartz diorite is evidence they have undergone a regional metamorphic event. The contortion into tight ptygmatic folds of small granitic dykes in quartz diorite outcrops near the Nashwaak Granite attests to a compressional metamorphic event. Mineralogically however, there is no evidence that suggest the rocks have undergone more than a low grade of metamorphism. With the exception of location C1, the granites are not foliated, indicating their emplacement post dated metamorphism.

The rocks are calc-alkaline and metaluminous with the exception of the granites which are peraluminous. This is

consistent with trends seen in chemical variation diagrams which suggest that, excluding the granites, the rocks are co-magmatic. It is proposed here that the latent heat of crystallization from cooling gabbro, diorite, and quartz diorite magmas melted enclosing country rock producing a melt of granite composition.

All rock types have been effected to various degrees, by a late stage K, Rb-metasomatism.

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CHAPTER I

Introduction

The study area, the western most section of a claims group owned by Kidd Creek Mines Ltd., is located in the vicinity of Sisson Brook in York County, approximately 100 kilometers north-west of Fredericton, New Brunswick.

While employed by Kidd Creek Mines Ltd., (then Texasgulf Inc.) the author was assigned the task of producing a detailed geological map over the extensions of a grid co-ordinate system cut into the forest several months previous. In all, approximately 70 kilometers of line were mapped.

1.1 Property Access

Access to the property can be gained through the Valley Forest Products Ltd. lumber road followed by a side lumber road at mile 25, known as the Fire Road (fig.1). These roads are well maintained. The secondary roads on the property are constantly being built by an ongoing logging operation. This is increasing the number and accessibility of the outcrops. Several outcrops were found only after overlying till had been bulldozed.

1.2 Previous Work

The most recent work on the area was done by McQuade (1979) who, with the aid of R.F.Mann, mapped the eastern most section of the grid.

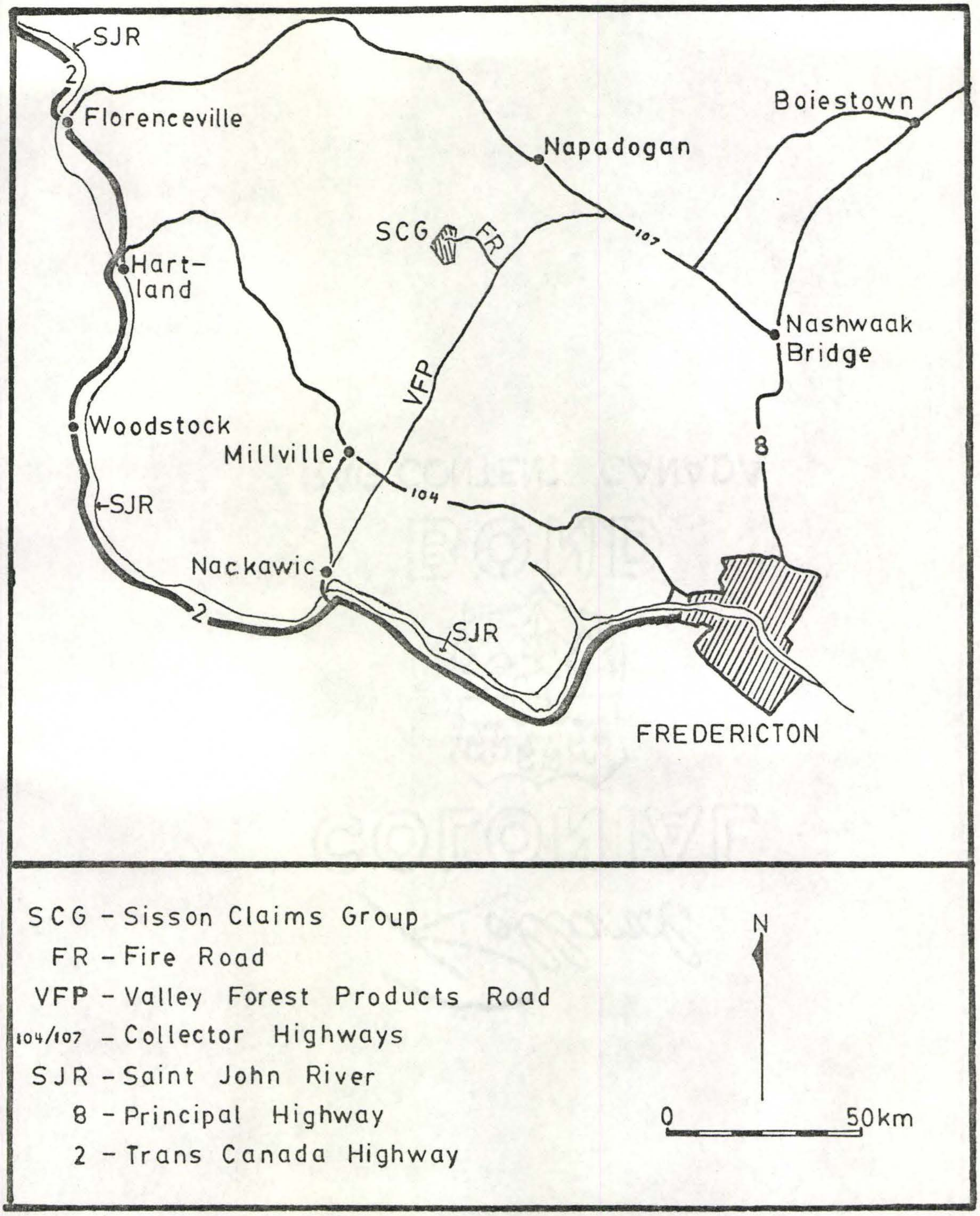


Figure 1 - Location Map.

Moore (1978, Personal Communication) reported on work done by Kidd Creek Mines Ltd. (geophysical / chemical surveys and diamond drilling). Previously, Penarroya Canada Ltee did similar work as that described by Moore.

1.3 Statement Of The Problem

Metamorphism has made it difficult to determine the protolith of individual rock suites in the field. The aim of this study is to assign them a genetic name in order to better understand the occurance of Cu, W, and Mo mineralization which may or may not be economic.

Petrographic and geochemical analysis will attempt to; 1) classify the rocks, 2) interpret their genetic relationships, 3) discuss their origin.

Limited outcrop and poor accessibility in the past are the primary reasons that little geological information is available on the Sisson Brook area (Moore, Personal Communication). While the problem of accessibility has been greatly alleviated, that of outcrop scarcity remains an obstinate frustation. The low lateral extent of individual outcrops (the maximum being on the order of 10 x 20 meters, with most far less) also lends to the problem of correlating rock types.

CHAPTER II

Regional Geology

The Sisson Brook area lies in the south-central portion of the Central Plutonic Belt, a south-west - north-east zone of metamorphosed volcanic and sedimentary rocks. This entire sequence was subsequently intruded by plutonic rocks. The metasediments / volcanics and plutonics comprise the Miramichi Anticlinorium or Massif (Fyffe, et al, 1981).

The oldest strata are Cambro-Ordovician slates, argillities, graywackes, and quartzose sediments with relatively minor amounts of grit, limestone and conglomerates (Anderson,1968). Ordovician subduction along a continental margin (the Miramichi Massif) resulted in volcanic activity which produced mafic and felsic volcanic rocks (Fyffe et al, 1981). Anderson (1968) describes andesitic and basaltic volcanics of Devonian age to the immediate north and west of the map area. Devonian plutonic sequences, associated with the Acadian Orogeny, intrude the Massif (Fyffe et al, 1981). These intrusives are dominantly granitic in composition although quartz diorites, diorites and gabbros occur as well (Anderson, 1968, Fyffe et al, 1981).

In the map area, there are three principal rock associations in rough east to west direction - meta sediments, gneissic rocks and granites respectively. The meta sediments are argillaceous, that is slates and argillite, with minor graywacke and mafic volcanics. They correspond to the Tetagouche Group in the Bathurst-Newcastle area (Moore, Personal Communication). The "gneissic" zone was described by Anderson (1968,p.17) as one of gneiss, schist, hornfels and injected lit par lit granite. The granitic zone in the west is described as one of biotite granites and quartz monzonites known as the Nashwaak Granite (Moore,1978,Personal Communication).

Anderson (1968) describes rock types "immediately" west of the Nashwaak granite (i.e. just outside the map area) which may constitute a fourth rock association or zone. In particular he states (1968,p.32) "The basic coarse-grained igneous rocks in the northern section of Millville map area and along the western margin of the Nashwaak granite body in the coldstream map-area vary in composition from quartz diorite (here and there approaching a granodiorite with as much as 20 per cent quartz) to gabbro."

CHAPTER III

Petrography

3.1 Introduction

Mapping showed that lithological variance was greatest in a north to south direction. This means east - west trending geological contacts. Thus samples were collected in a north - south line from the granite (Nashwaak Granite) in the north to the gabbro in the south.

The nature of the outcrop, and therefore the ease of sampling, played a part as well in sample selection. For example, many of the outcrops are quite rounded and smooth making sampling very difficult. As a result many samples obtained are of use for a general lithological description but are unreliable for petrographic or geochemical study. In order to obtain a good cross section of different lithologies, twenty samples were chosen for petrographic study, sixteen of which were analysed chemically.

The terms " outcrop " and " sub-outcrop " are used to distinguish insitu and displaced rocks respectively. A sub-outcrop is defined as a unit of rock that has been displaced a very short distance from its original site (as a general rule of thumb no more than 20 meters). In this regard it would still serve as a representative in the over all areal distribution of lithologies.

In the field, the rocks were classified into groups based on textural and mineralogical characteristics on the outcrop/hand sample scale. These are :

A) Granite

B) Biotite Plagioclase Gneiss

C) " Tuffaccous " Rock

D) Diorite

E) Meta Gabbro

F) Fine Grained Meta Sediment - "Biotite Hornfels".

The following is a summary of the important mineralogical and textural features of representative outcrop/ sub-outcrop as well as the main petrographic characteristics of thin sections cut from their samples.

3.2 Unit Descriptions

Based on the mineralogy, modes and textures seen in thin section, five basic lithologies can be defined in the map area. These units are respectively :

A) Granites (Nashwaak Granite)

B) Quartz Diorite

C) Diorite

D) Hornblende Plagioclase Gabbro

E) Pelitic Meta Sediment

The meta sediment is not dealt with in any detail from this point. The Biotite Plagioclase Gneiss and "Tuffaceous" Rock constitute the quartz diorite. Figure 8 shows modal data from the rocks, given in table I, plotted in the Q-A-P classification scheme after Streckeisen (1976).

A) Granites - For the most part the granites are found as sub-outcrop. In the two that occur as outcrop (C1, C10), a jointing pattern oriented approximately 308 / 65W can be seen. A distinction can be made between three types of granite:

1) Samples C72B, C73, C74 possibly C10: A coarse grained, pinkish white, biotite granite in which, C10 excluded, alkali feldspar forms megacrysts averaging 0.5 cm in diameter, giving a sub-porphritic texture. The remaining felsic constituents, plagioclase and quartz, show a more granular character.

II) Sample C 1 : An orangish, highly weathered granular granite rich in quartz (38.4%). This sample texturally and mineralogically resembles the granite dykes found in some proximal quartz diorite outcrops.

III) Sample C 76: A finer grained two mica granite.

Quartz - Quartz in all granite samples exhibits strong undulatory extinction and sutured boundaries. Traces of myrmekitic texture are found between quartz and plagioclase were the latter border alkali feldspar (even in the granitic dyke described in the discussion of sample C 18 - see Appendix A). Trails of fluid inclusions can be seen in many grains.

Plagioclase Feldspar - Pericline, albite and to a lesser extent combined carlsbad / albite twins occur in plagioclase, at times coupled with concentric, normal zoning. Its composition varies between An_{10} and An_{30} .

There are two principal zones where sericitic alteration is most severe. These are in the cores of some zoned crystals and in the plagioclase inclusions within microcline. Outside of these zones the grains are fairly fresh.

Small laths of biotite,and in C76 primary muscovite, are common as inclusions.

Alkali Feldspar - The alkali feldspar is microcline with perthite occuring in all samples. Perthite can form by unmixing, at lower temperatures, of homogeneous alkali feldspar (Tuttle & Bowen 1958). or by the simultaneous crystallization of Na and K rich feldspars followed by replacement of Na-feldspar by K-feldspar, or visa versa (Marmo, 1971). Many contain fine, regular perthitic intergrowths which is attributed to the mechanism of Tuttle and Bowen (Deer et al, 1966). Others contain larger irregular patches of plagioclase which in some cases is intergrown with quartz, so called myrmekitic texture. The origin of these latter perthites is attributed to a replacement process, in this case, K-feldspar replacing Na-feldspar (Deer et al, 1966, Marmo, 1971). The perthites in the Nashwaak granites are texturally of two types, and therefore two origins. Unmixing of an originally homogeneous alkali feldspar for the perthites containing fine regular intergrowths and replacement due to some K-metasomatism for those containing larger irregular intergrowths. The former predominates over all. Small laths of biotite are common inclusions, generally showing chloritic alteration.

Biotite - Biotite is primary but may occur rarely as an alteration product of hornblende (noted in samples C73 and C74). It is pleochroic from a pale yellowish brown to a deep reddish brown.

Minor chloritic alteration occurs along cleavage planes often parting the biotite crystal and in some cases completely altering it. Minute pleochroic halos due to zircon inclusions are common along with euhedral apatite and magnetite (Apatite is relatively rare in samples C1, C10 and C76)..

Muscovite - Primary muscovite is most common in sample C76 but occurs as traces in C73 and C74.

B) Quartz Diorite

The quartz diorite can be seen in contact with the granite in two places, at sample location C10 and C72. In both cases the contact is sharp and undulatory producing a small (roughly 2 - 5 cm)fine grained to aphanitic chill zone in the quartz diorite. In general, the grain size of this unit is finest when proximal to these granite contacts or in the area of abundant small granite dykes (locations C17 - C26). It is also here that the gneissic banding is most pronounced. This suggests that locally, the foliation is due to emplacement of the granite. However at location C18, the injection of a small granitic dyke modifies a pre-existing foliation (see discussion of C18, Appendix A), showing the granite to be post foliation.(This foliation is a weakly developed regional feature, seen best in the gabbros and diorites, with a north-north-east - south-south-west trend). As can be seen on the map (rear pocket) there are several deviations from this trend which correlate to the above mentioned areas of more pronounced foliation.

In the southern part of the quartz diorite at location C53, lit par lit granites are different than those in the more northern part. For example, in the area of C17 and C18 (northern part) the granite dykes are a coarse, orangish, quartz rich,mafic poor rock. Those at C53 (southern part) however are a pink,more mafic, very quartz rich,plagioclase poor rock.

Most of the outcrops show a consistent jointing pattern at roughly 306/65W. On the whole, the quartz diorite is medium to coarse grained with mafic minerals comprising the finer constituent, felsic minerals the coarser.

Quartz - Though the degree varies somewhat, the quartz exhibits undulatory extinction with essentially sutured borders. It is essentially inclusion free although trails of fluid inclusions are seen in C72A and somewhat in C53.

Plagioclase Feldspar - Plagioclase is well twinned with combined carlsbad/albite being the most abundant type followed by albite and pericline twinning. Many crystals show concentric normal zoning along with twinning. Overall, the crystals are fairly fresh having undergone only a low degree of sericitic alteration. The composition varies between An_{20} and An_{35}.

Biotite - Examples of both primary and secondary biotite can be seen in all thin sections. Secondary biotite occurs as an alteration product of hornblende either as partial rims, along cleavage, or as psuedomorphs after hornblende. In general, primary biotite is a higher birefringent more pleochroic form.

The biotite in the more northerly sections show pleochroism from pale brownish yellow to a deep reddish brown. Those in the southerly sections (i.e. C53(I), C59(II), are yellowish green to a deep olive green . The color difference may be attributed to a changing Ti / Fe^{3+} ratio with larger values giving the more reddish color (Deer et.al., 1966). This arquement is substantiated somewhat by the relative scarcity of sphene in the southerly sections.

In all sections studied, some degree of chloritic alteration occurs along cleavage planes often parting and warping the biotite where chlorite growth continues. Minerals found as inclusions in biotite include small euhedral apatite, magnetite, and sphene. Pleochroic halos from zircon inclusions occur in all but the more southerly sections C53 (I) and C59(II) where sphene is comparably rare as well. In these two sections quartz is an abundant inclusion mineral. Remnant pyroxene grains are associated with biotite in some sections.

Hornblende - Hornblende is found in nearly all quartz diorite sections occuring as anhedral to subhedral crystals. It is pleochroic from a pale yellowish green to a deep green. Many grains show a simple twinning and a poikilitic texture is very common with hornblende encompassing quartz, sphene, rarely plagioclase and quite frequently apatite.

Sphene - Euhedral to subhedral sphene is very common in the northerly samples, while towards the south it is less abundant and far more altered. Sphene replacement by magnetite is quite common.

C) Diorite

Owing to their scarcity only two outcrops of diorite were studied. These are sample locations C32 and C50. No contact relationships with other rock units are exposed. The diorite is a dark medium to coarse grained foliated rock. At location C32 quartz veining and granitic dykes occur. At location C43 (diorite at line 10 south / 7 + 60 west) similar quartz veining cross cuts granite dykes. A parallel set of quartz veins oriented at roughly 315/72 W occurs at C43 and a planar fracture system or micro jointing with similar orientation is seen at location C32.

Quartz - Quartz is interstitial in diorite, showing planar boundaries, some undulatory extinction, and in some trains of fluid inclusions.

Plagioclase Feldspar - Pericline, combined carlsbad/albite and albite twinning are common. Normal and patchy concentric zoning is also common especially in grains showing no twinning. Its composition ranges from An_{45} to An_{55}. Plagioclase has suffered little or no sericitic alteration.

Biotite - Biotite is an alteration product of hornblende (found as subhedral grains or pseudomorphs after hornblende)

With the exception of the biotite in C32, it is fairly fresh, though chloritic alteration can be seen in both C32 and C50. It is pleochroic from a pale yellow to deep reddish brown.

Zircon, common as an inclusion in C32, is not seen in C50. The biotite in the latter is relatively inclusion free while that of C32 shows inclusions of euhedral, apatite and opaques (magnetite, pyrite) besides zircon.

Hornblende - Hornblende occurs as anhedral to subhedral crystals. It is pleochroic from a pale greenish yellow to deep green. Poikilitic texture is common with hornblende encompassing small plagioclase grains and quartz. Some anhedral sphene grains and apatite occur as inclusions in C50 while magnetite makes up the brunt of inclusions in C32.

D) Gabbro

Of the four examples of gabbro studied,only one, C59 (I) shows a contact relation where it is found in a sharp undulatory contact with C59 (II) a quartz diorite. The absence of the dioritic unit between the gabbro and quartz diorite suggests it may pinch out towards the west. This cannot be verified however due to poor outcrop control.

The gabbro is a dark, coarse grained, foliated rock. Location C45 seems to have undergone the greatest amount of alteration on both outcrop and thin section scale (see appendix A). Late stage (post foliation) veining occurs at locations C45 and C66 with quartz and granitic veins found in the former and latter respectively.

Quartz - Quartz occurs only in accessory amounts and is interstitial, thus exhibits planer boundaries. Extinction is straight with only a weak undulatory extinction noted in some grains of samples C59 (I) and C66. Some grains contain minute fluid inclusions.

Plagioclase Feldspar - Twinning according to the pericline, combined carlsbad / albite and albite twin laws occur in plagioclase. Quite often these are accompanied by a normal or patchy concentric zoning and / or wavy extinction. Because of extensive sericitic alteration (C66 is an exception) these features are often destroyed, but where possible it was found the plagioclase composition ranges from An_{45} to An_{56}. Small subhedral opaques (magnetite, pyrite?) are found as inclusions in some plagioclase.

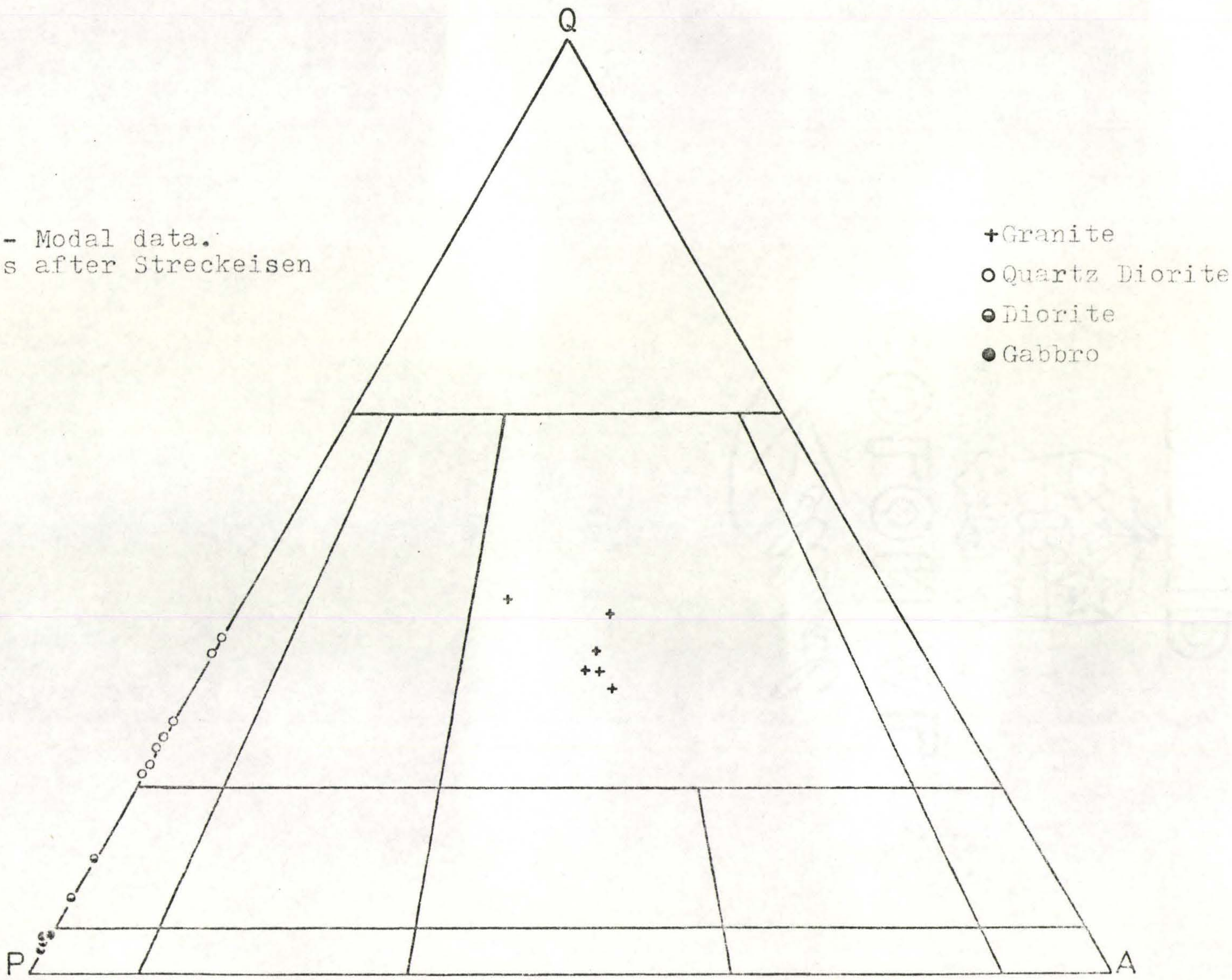
Biotite - Biotite occurs only as an alteration of hornblende. Pleochroism is from a light brownish yellow to pale brown colour. In many cases biotite has undergone intense chloritic alteration often leaving chloritic psuedomorphs of biotite. Magnetite is the common mineral found as inclusions, though C59 (I) shows small anhedral sphene while C66, some euhedral apatite as well as magnetite.

Hornblende - In sample locations C45 and C59 (I), hornblende is highly altered often occurring only as small rounded remnants. In sections C66 and C68 hornblende occurs as more subhedral grains. Pleochroism is from a pale yellowish to green color. In sections C59 (I) and C66 hornblende poikilitically

Table 1 Modes (Percents). P.F. - Plagioclase Feldspar; A.F.-Alkali Feldspar; Bio.-Biotite; Hbld.-Hornblende; Musc.-Muscovite; Sph.-Sphene.

Sample	Quartz	P.F.	A.F.	Bio.	Hbld.	Musc.	Sph.	Opaques	
C73	27.7	27.1	31.3	13.9	-	-	-	-	
C72B	28.9	28.5	36.7	5.9	-	-	-	-	
C76	33.9	23.4	30.5	7.6	-	4.6	-	-	
C74	30.1	28.6	34.0	7.3	-	-	-	-	
C1	38.4	34.0	23.4	4.2	-	-	-	-	
C10	32.3	26.2	35.1	6.4	-	-	-	-	Granite
C72A	15.4	48.1	-	36.5	-	-	-	-	
C5	10.9	40.6	-	22.4	26.1	-	-	-	
C17	12.6	37.5	-	25.2	23.3	-	1.4	-	
C22	15.9	42.9	-	22.6	17.5	-	1.1	-	
C47	23.2	38.6	-	36.1	-	-	1.8	-	
C53	22.7	42.6	-	11.0	23.7	-	0.5	-	
C59II	12.2	41.9	-	10.9	32.6	-	1.6	0.8	Quartz Diorite
C32	5.2	37.4	-	17.6	37.8	-	-	-	
C50	3.2	36.9	-	24.5	39.4	-	-	-	Diorite
C59I	1.2	37.4	-	5.1	52.8	-	2.4	1.1	
C45	1.1	25.6	-	30.9	39.6	-	2.1	0.7	
C66	1.6	43.2	-	4.7	48.9	-	2.4	1.1	
C68	1.2	39.6	-	6.4	51.5	-	-	1.3	Gabbro

Figure 2 - Modal data.
Boundaries after Streckeisen (1976).



encloses quartz plagioclase, anhedral sphene (in C59 (I)) and euhedral apatite (C66). In all sections some magnetite inclusions, often along cleavage planes can be seen.

3.3 Metamorphism

In the gabbro, diorite, quartz diorite and location C1 of the granites (other granite excluded) a regional foliation is produced by the parallel alignment of mafic minerals. This foliation is interpreted as a consequence of regional metamorphism rather than flow mechanisms during emplacement for the following reasons: 1) it is evident in more than one rock type of different ages with the same orientation (roughly N N E - S S E); II) it occurs in outcrops well away from geological contacts in the above orientation but is modified near such contacts;III) the highly contorted nature of small granitic dykes in the location of C17 - C26 attests to a compressive metamorphic event.

However, if the foliation is metamorphic, it formed only under very low grades of metamorphism as there is no evidence either texturally or mineralogically, for higher grades. Textures shown by quartz are igneous i.e. the straight extinction in gabbros and diorite, and the highly sutured nature of quartz - quartz grain contacts in the more felsic rocks (especially the granites). The absence of metamorphic mineral assemblages (in the plutonic rocks) such as zeolites, garnets, alumino - silicates, cordierite, and the stability of chlorites, muscovites (primary in the granites, secondary plagioclase alterations in the remaining rocks) and biotite hornblende facies again argues for a very low grade of metamorphism (Winkler, 1974).

The lack of foliation in all the granites but C1 shows they were not affected and therefore post-dated the metamorphism.

CHAPTER IV

Geochemistry

Sixteen of the twenty samples studied in thin section were selected for major and trace element analysis (the analytical procedure is given in appendix B). The results are given in tables 2, 3, and 4. The purpose of this analysis is to : I) Chemically classify the rocks comparing the results with the mineralogical classifications of chapter III;

II) To help discern a relationship between rock types;

III) To help determine their origin.

CIPW and Meso-norms were calculated for each sample to aid in the chemical classification and problem of origin.

4.1 Chemical Classifications

Figure 3 shows the meso-normative composition of the rocks in the Q - Ab - Or diagram of Tuttle and Bowen (1958). Figure 4 shows the meso-normative data plots within the Q - P - A classification scheme after Streckeisen (1976). Normative data indicates that the rocks are calc-alkaline. This is supported by the AFM plot (fig. 5) where the trend for rocks of calc-alkaline affinity from Carmichael et al. (1974,p568) is plotted with data. The trends seen in figure 6 (a) i.e. the negative correlations of Ca , Mg , Fe and positive correlation of K with the Modified Larsons Index, is compatible with the predicted trends for calc-alkaline rocks (Birk,1978).

In all samples the value of $Al_2O_3 : CaO + Na_2O + K_2O$ is greater than one, which according to Carmichael et.al. (1974)

Table 2

Whole Rock Analysis in
Weight Percent Oxides
Normalized to 100 %

	Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	loss on ignition
	C73	67.89	15.50	4.45	1.14	2.20	3.09	4.81	0.66	0.05	0.21	0.8
	C72B	70.06	14.8	3.86	1.42	1.74	3.02	4.31	0.56	0.08	0.15	1.08
	C76	73.02	14.59	2.06	0.8	1.5	3.62	3.98	0.24	0.06	0.13	0.9
	C74	66.79	15.70	4.96	1.74	2.89	3.57	3.26	0.75	0.08	0.28	0.9
Granite	C1	76.45	11.6	1.15	0.69	0.55	4.21	5.16	0.11	0.03	0.05	0.4
	C72A	63.74	16.53	5.97	2.96	4.15	2.98	2.22	1.06	0.16	0.22	1.91
	C5	59.00	17.43	6.03	3.84	5.42	4.93	2.02	0.95	0.13	0.26	1.15
	C17	59.47	17.66	6.19	3.67	6.13	3.87	1.65	1.00	0.11	0.24	0.82
Quartz	C47	65.94	16.75	4.34	1.87	4.03	4.60	1.55	0.67	0.08	0.17	1.14
Diorite	C53	63.46	17.10	4.66	2.8	4.58	4.21	2.16	0.77	0.09	0.17	0.7
	C32	54.59	19.14	7.77	4.52	5.96	3.42	2.82	1.20	0.14	0.45	1.3
Diorite	C50	53.06	19.41	7.84	4.93	8.82	3.24	1.12	1.27	0.13	0.18	0.9
	C45	47.47	19.57	9.67	7.08	10.02	2.53	1.60	1.64	0.20	0.22	1.43
	C66	47.6	19.32	10.95	6.00	10.12	2.73	0.72	2.02	0.21	0.33	0.8
Gabbro	C68	46.04	20.86	10.09	7.10	10.93	2.39	0.56	1.75	0.16	0.13	1.1

Table 3 Trace Elements (ppm).

Sample	Ce	Nd	La	Ba	Rb	Sr	Y	Zr	Nb
C73	164	52	75	1321	160	206	31	380	23
C72B	142	54	78	668	124	277	25	296	19
C76	41	26	23	303	210	109	31	152	21
C74	153	53	101	1038	146	254	35	416	26
C1	110	43	79	264	134	106	20	152	17
C72A	160	55	80	315	147	318	34	250	19
C5	49	31	21	260	141	691	31	176	13
C17	36	27	18	274	83	685	25	174	15
C47	36	23	0	71	47	633	37	95	11
C53	35	19	11	575	74	619	11	184	14
C32	56	37	25	274	380	663	34	167	13
C50	29	23	0	116	61	596	22	98	10
C45	43	33	5	121	200	808	30	106	10
C66	62	27	62	219	79	511	5	205	16
C68	36	30	0	86	40	1157	24	95	8

Table 4 Trace Elements (ppm) continued

Sample	Cr	Co	Pb	Zn	As	V	Ni	Cu	Mo	W
C73	34	16	38	67	0	65	13	3	2	3
C72B	30	9	31	50	0	42	22	14	3	2
C76	25	0	21	42	0	21	28	4	2	2
C74	42	12	31	75	0	61	35	4	4	5
C1	56	0	17	26	0	0	30	0	3	4
C72A	34	18	26	127	0	144	19	18	4	<1
C5	50	21	23	76	0	115	42	14	3	<1
C17	48	20	24	66	0	162	33	62	1	3
C47	15	39	15	110	0	307	25	36	4	2
C53	37	7	25	50	0	78	41	3	1	<1
C32	29	24	20	86	0	205	53	327	4	19
C50	58	24	19	83	0	228	44	34	2	2
C45	27	41	18	102	0	300	55	34	8	1
C66	30	14	21	97	0	70	27	25	0.5	1
C68	57	32	15	89	0	304	46	51	5	1

Figure 3 - Meso-norm data with PH_2O isobars after Tuttle and Bowen, (1958).

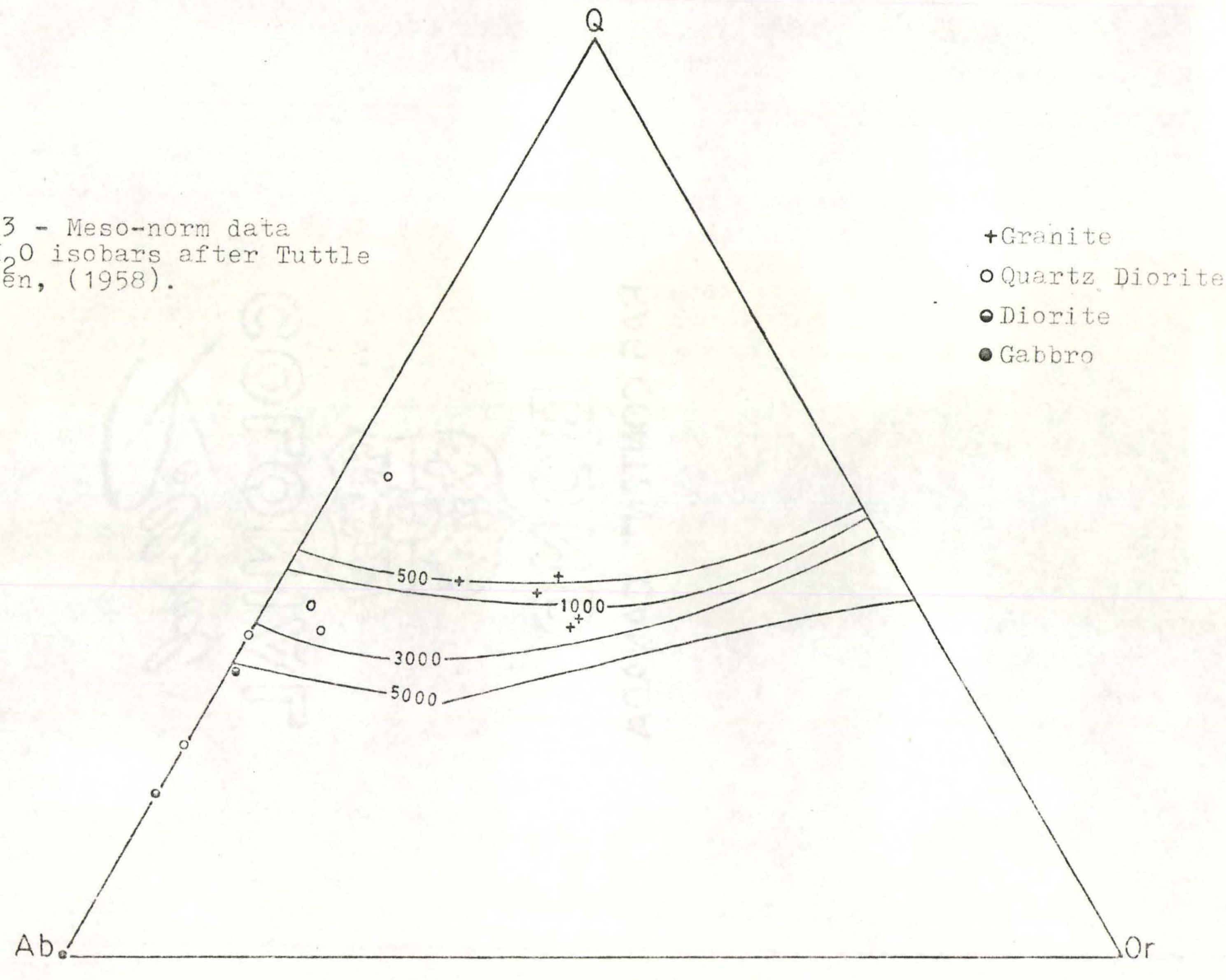


Figure 4 - Meso-norm data. Boundaries after Streckeisen (1976).

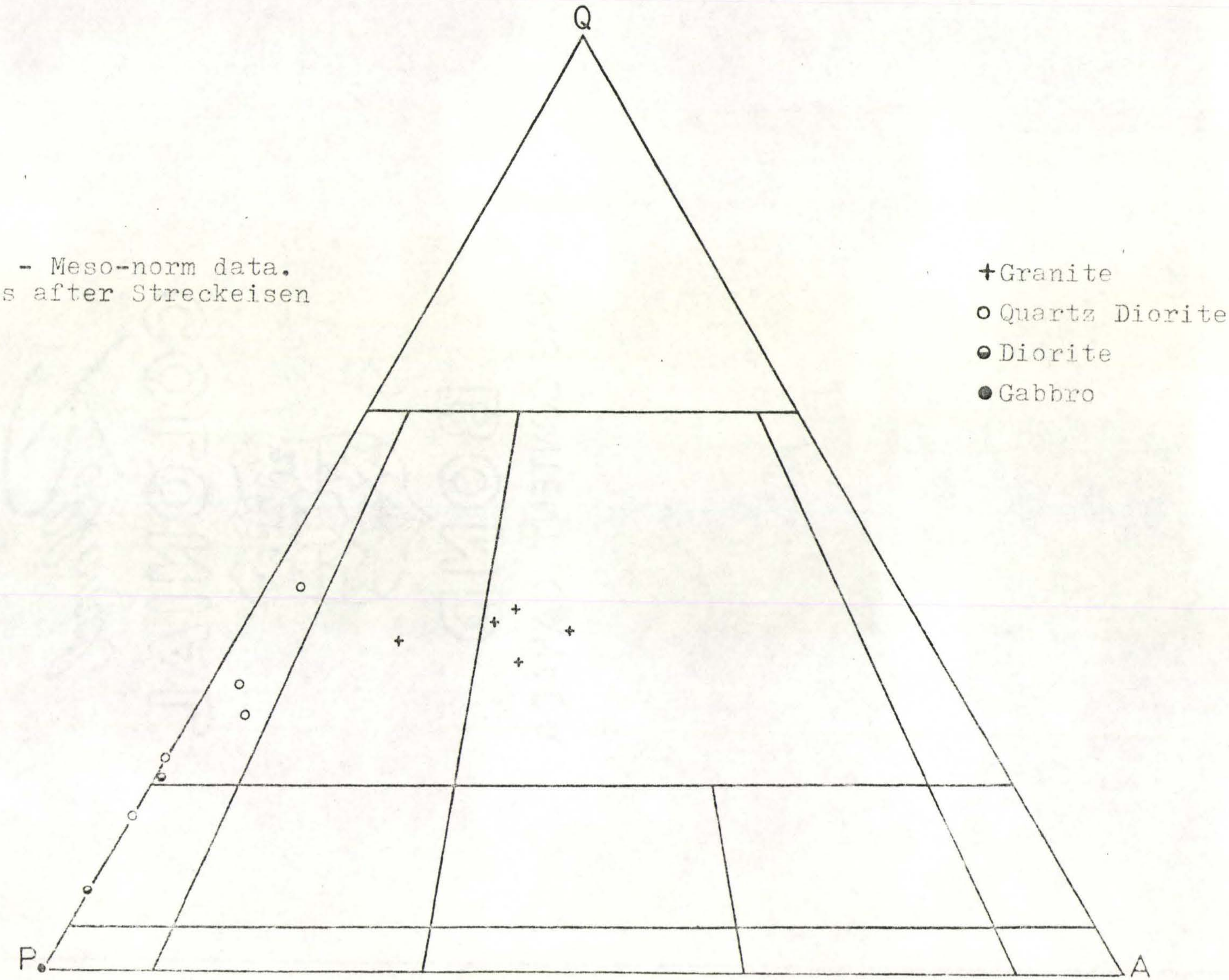
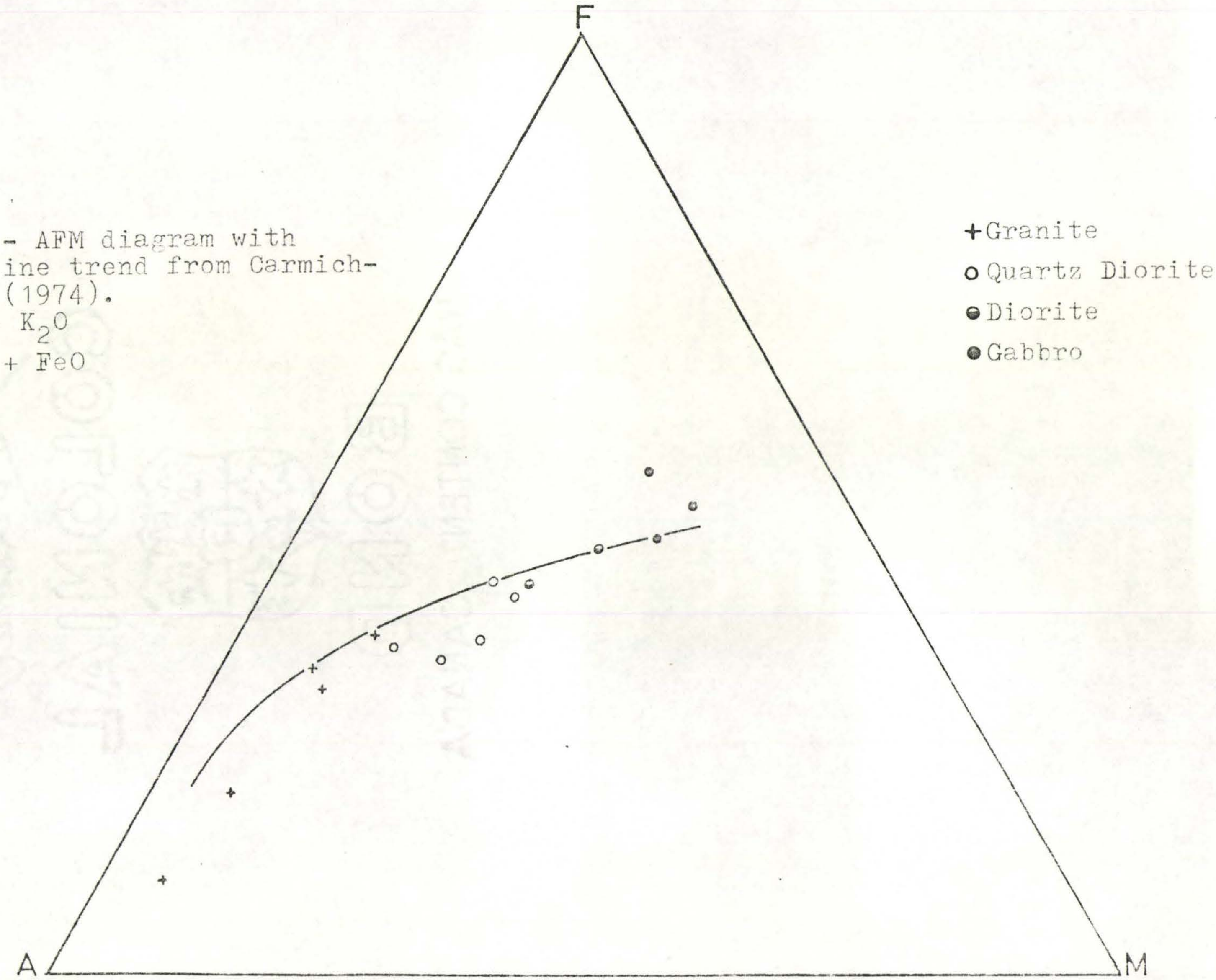


Figure 5 - AFM diagram with Calc-alkaline trend from Carmichael et al.(1974).
$A = Na_2O + K_2O$
$F = Fe_2O_3 + FeO$
$M = MgO$



classifies them as peraluminous. Mineralogically however, with the exception of the granites they are more akin to a metaluminous classification by the same scheme. Also, calc-alkaline rocks are seldom Peraluminous. This would suggest the granites may have a separate origin than the other units.

By the criteria of Chappel and White (1974) the granites are S - types. Table 5 lists characteristics of both S - type, derived from sedimentary precursors, and I - types derived from an igneous parent (Heaman, 1981), as well as those of the Nashwaak Granite samples. By these criteria, the remaining rocks show an I - type affinity.

4.2 Chemical Trends

Binary plots of major oxides and trace elements against Modified Larsons Index were produced in order to investigate any trends that may suggest or refute a co-magmatic origin of the rocks. This would help interpret the field relation of rock types which, owing to their lithological sequence, seems to suggest a fractional crystallization origin with a mafic margin (gabbro) to a felsic core (Nashwaak Granite).

Figure 6 (a) shows major oxides VS Modified Larson's Index (M.L.I.). A strong negative trend occurs with CaO,Fe_2O_3, MgO and TiO_2. K_2O shows a somewhat weaker positive trend. Trace elements (fig. 6 (b)) do not exhibit as tight a trend as the major oxides but positive correlations are shown by Zr,Rb and Ba while Sr, exhibits a weak negative correlation.

The trends of Ba and particularily Sr reflect the sequence of feldspar composition. Sr shows a decrease with M.L.I.from

Table 5 Granitoid Clasification. After Heaman (1980).

	S-type	I-type	Nashwaak Granite
Mafic Minerals	musc,bio,gn,cd	bio,hb	bio
Accessory Minerals	mon,il,sph	sph,ap,mt	ap,mt(?)
Xenoliths	metasedimentary	mafic cognates	metasediment
Variation Diagrams	irregular	smooth	insufficient data
Associated Mineralization	Sn	porphyry Cu	nil
$Al_2O_3/Na_2O + K_2O + CaO$	>1.1	<1.1	>1.1
Normative Corundum	>1.0%	<1.0%	>1.0%
Compositional Variation	restricted	varied-associated with mafic rocks	insufficient data

musc - muscovite; bio - biotite; gn - garnet; cd - cordierite; hb - hornblende; mon - monazite; il - ilmenite; sph - sphene; ap - apatite; mt - magnetite the gabbros to the granites. Since Sr commonly substitutes for Ca in plagioclase (Hanson, 1978) it is supportive in expressing the plagioclase composition control on Ca content shown by the CaO trend in figure 6(a). Similarily, Ba which substitutes for K in alkali feldspar, supports the K_2O trend. Ba shows a slight, steady increase from the gabbros through diorite to quartz diorite, then a sharp increase in the granites, the only rocks in which K-feldspar occurs. Rb follows K_2O and substitutes for K into biotite (Hanson, 1978). Its correlation with M.L.I. is only slightly positive and the data is widely scattered. For this reason, the Rb vs M.L.I. plot is inconclusive.

The K / Rb ratios suggested by Shaw (1968) as another parameter in deciding genetic relationships is inconclusive as well. This is a result of the apparent enrichment of the rocks, particularily the gabbros and diorites in Rb, and to a lesser extent, K.Hanson (1978) states that the K:Rb ratios in more basic rocks such as gabbros and diorites are generally higher than in granitic rocks. This is practically the reverse of the situation seen here. C45 (gabbro) shows enrichment of Rb and K while C32 (diorite) shows enrichment of Rb. This can be seen in figure 7 where two general trends can be delineated; a highly variable Rb, nearly constant Sr content giving a verticle trend represented by the gabbros, diorites, and quartz diorites, and a more horizontal trend shown by the granites.

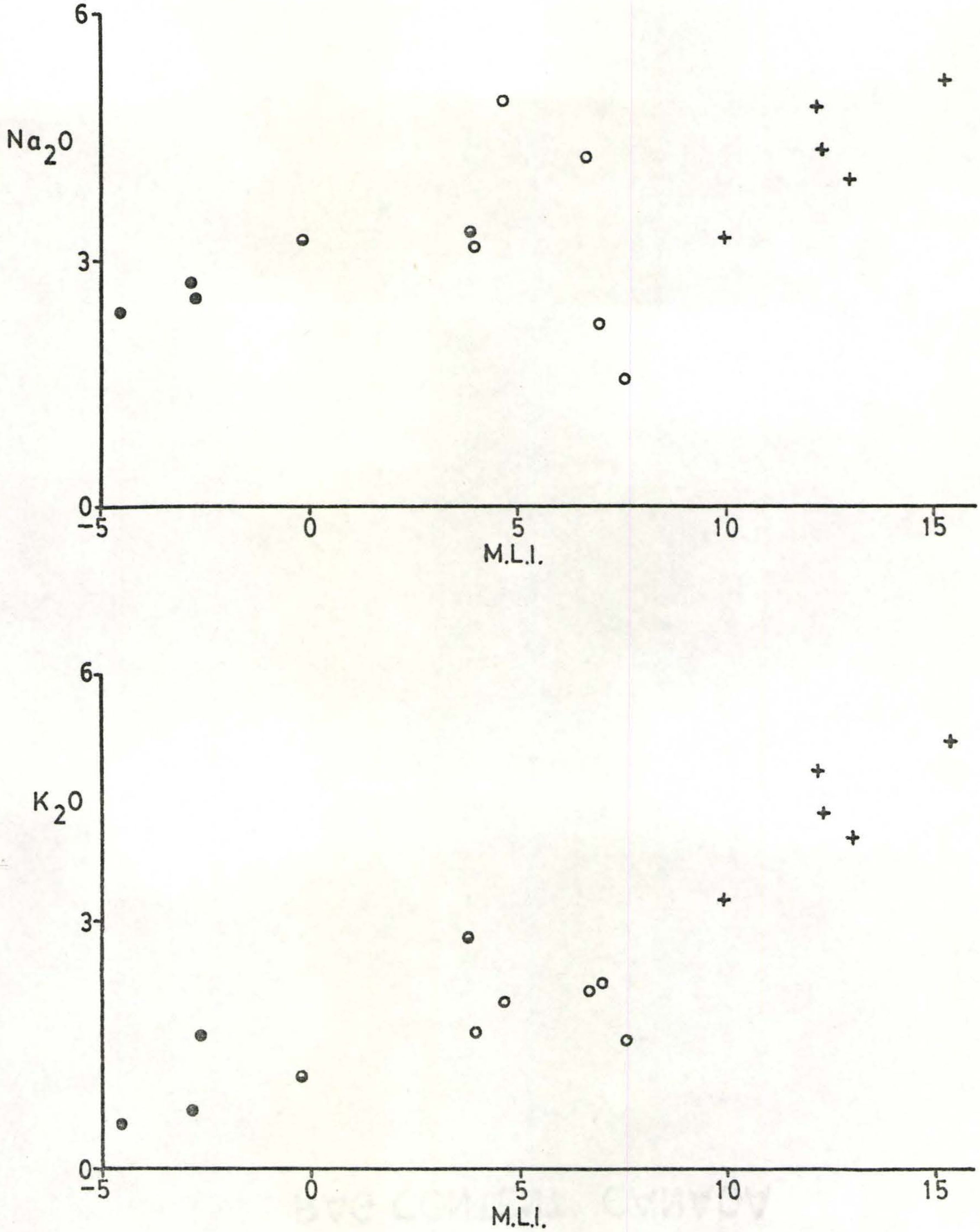


Figure 6 a) - Major Oxides (weight percents) vs Modified Larsons Index (M.L.I.).

+Granite
o Quartz Diorite
◒ Diorite
● Gabbro

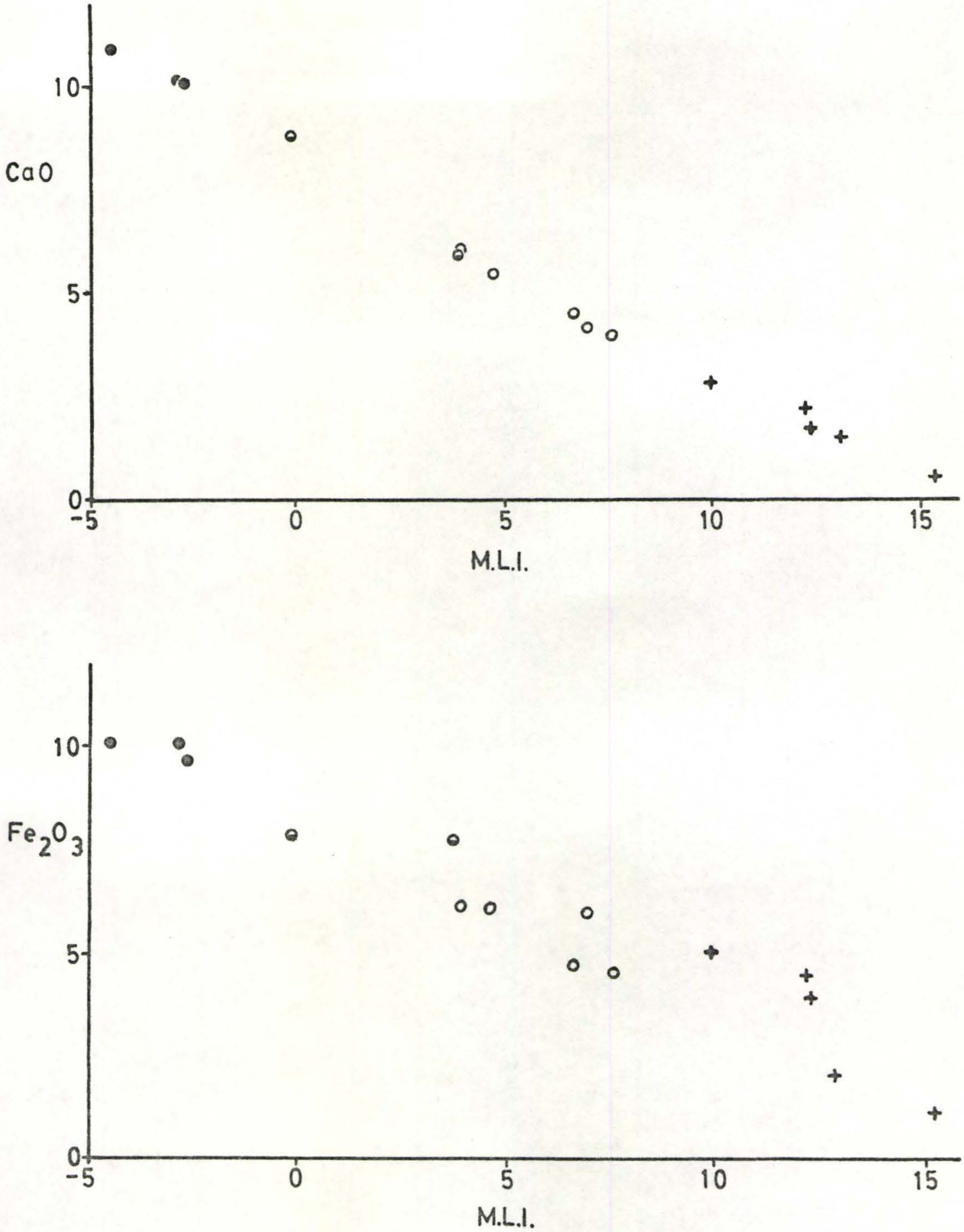
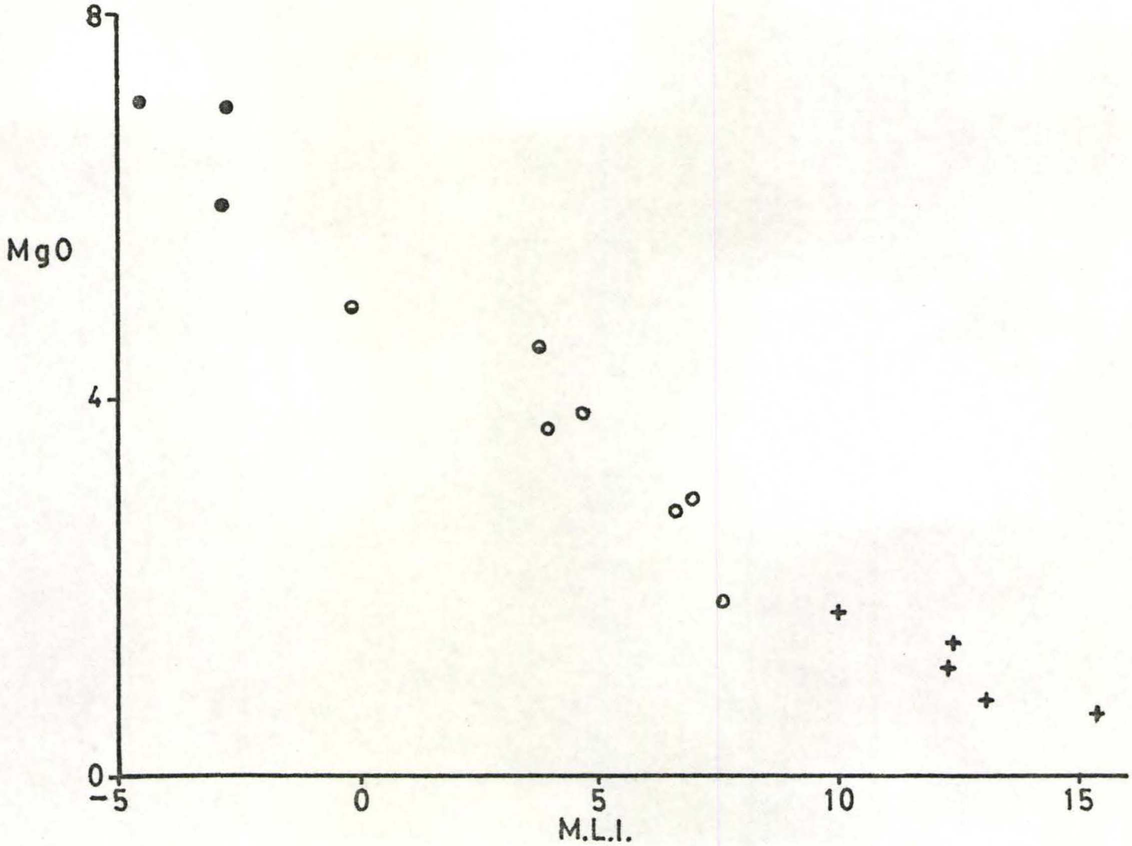


Figure 6 a) conti.



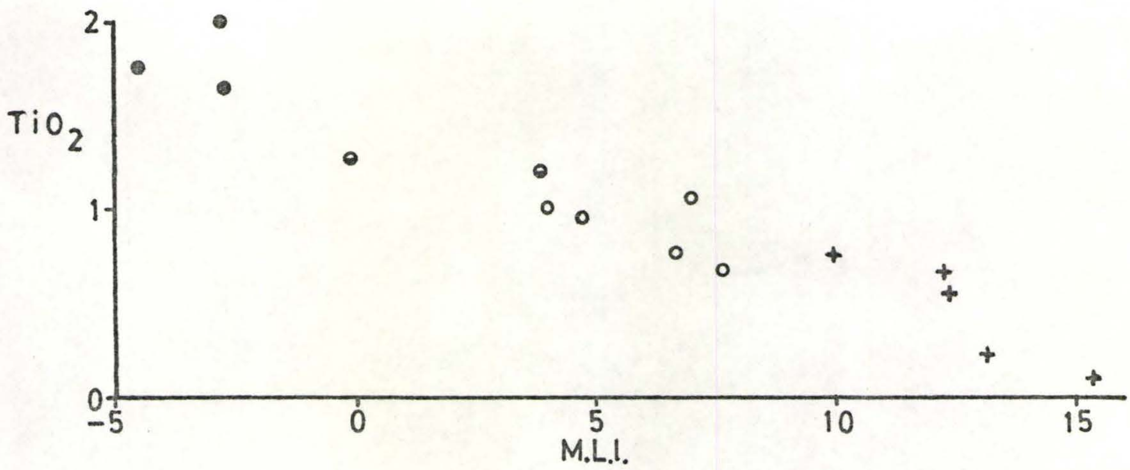


Figure 6.a) conti.

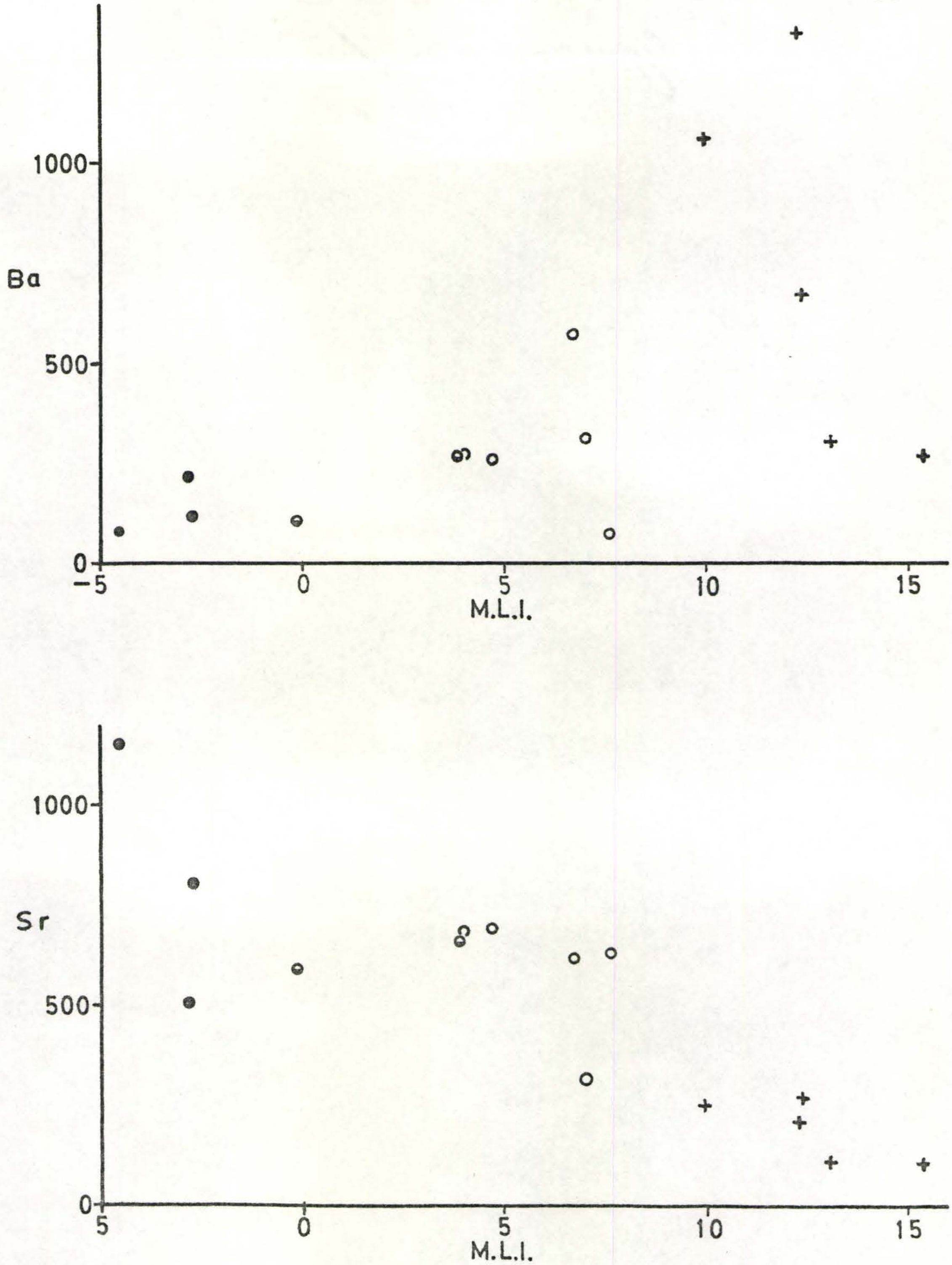


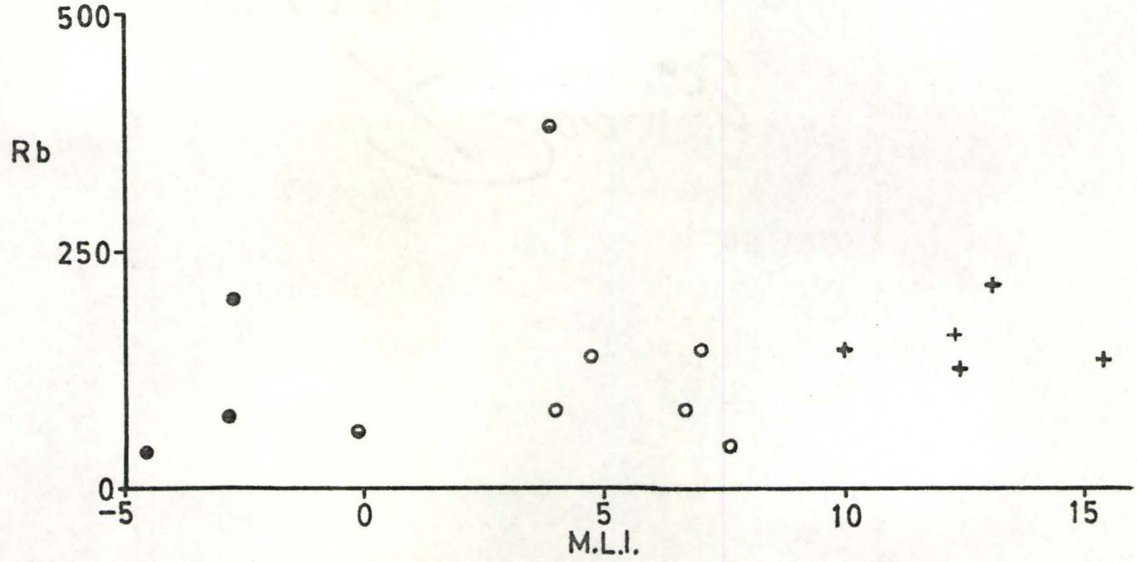
Figure 6b) - Trace Elements (ppm) vs Modified Larsons Index (M.L.I.).

+ Granite

o Quartz Diorite

Diorite

Gabbro



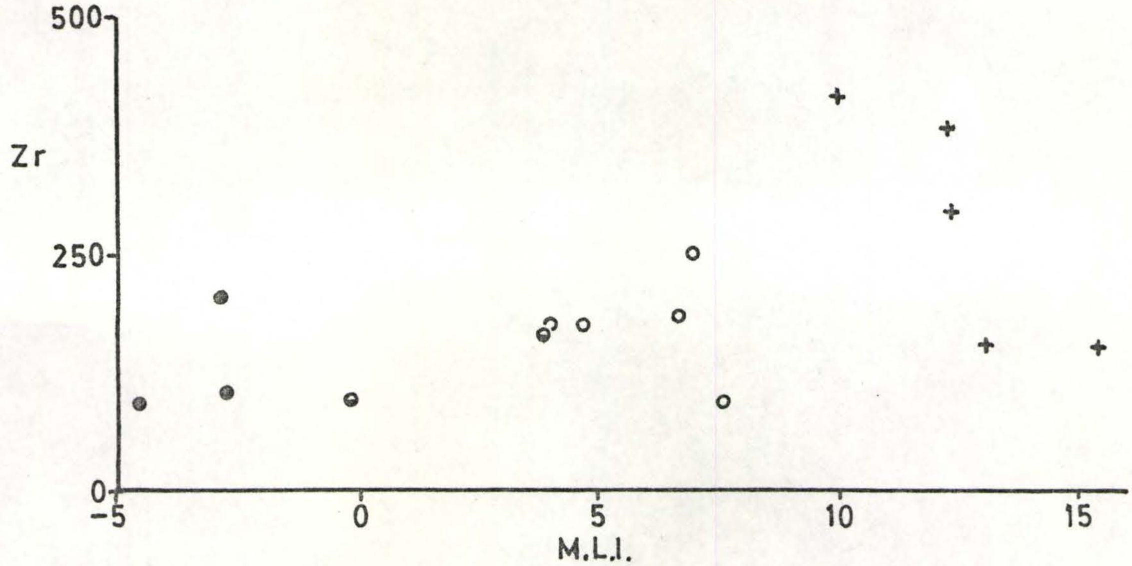


Figure 6b) conti.

Figure 7

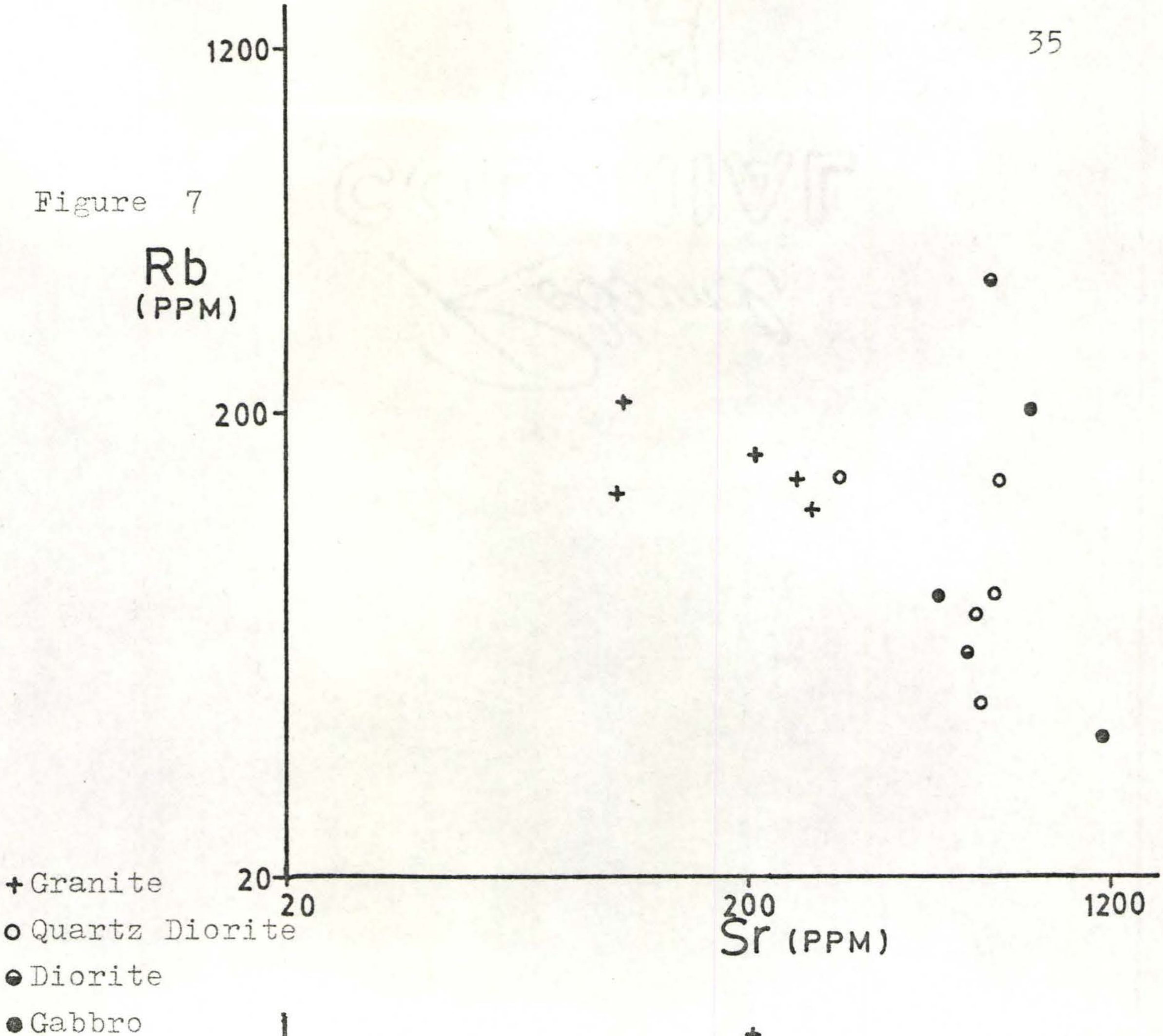
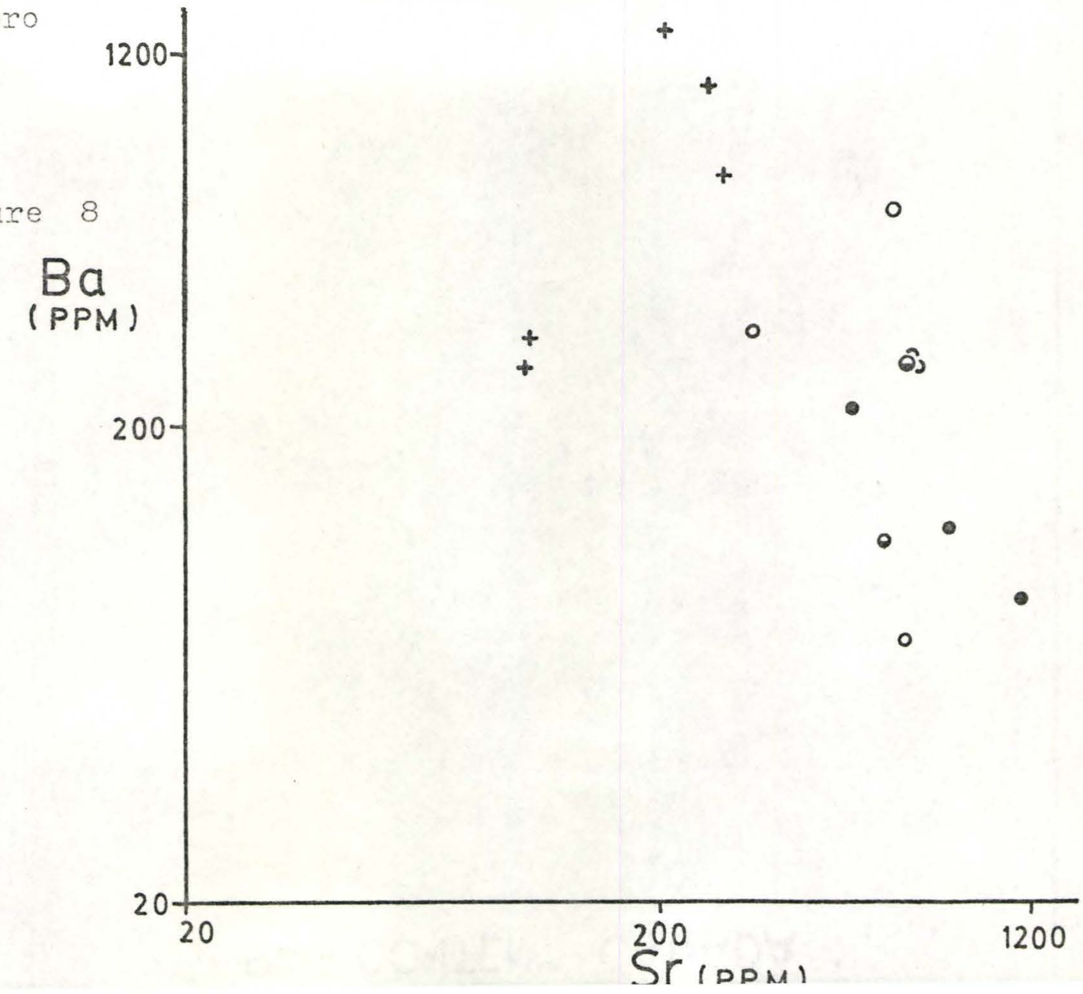


Figure 8



This together with the Ba vs M.L.I. plot of figure 6 (b), suggests that the granites may have a different origin. This is consistent with the S versus I - type and peraluminous versus metaluminous nature of the granites.

The gaps between the data plots on these diagrams are not significant because of the outcrop scarcity and subsequent low sample density.

The values of Cu, Mo, and W for the outcrops sampled are given in table 4. With the exception of C32 all are below background levels. Combined values of Cu, Mo, and W show a rough south eastward increase from the granite. It appears that the source of mineralization in which these metals occur is not related to the rocks studied in the map area.

4.3 Summary

Tables 2, 3, and 4 have grouped the samples by rock type in a rough north (C73, granite) to south (C68, gabbro) sequence. Outcrops C32 and C45 are farther north than their position in this sequence would suggest as they are found farther east along the N.E - S.W geological contacts. Also C72A is in contact with C72B and therefore farther north, but the remainder of the outcrops as shown, do form a north to south distribution.

From this, the following areal variations in chemistry from gabbros (south) to granites (north) can be seen:

1) steady decrease in Al_2O_3, total Fe, MgO and CaO.

11) slight increase in Na_2O, Rb / Sr ratio

111) pronounced increase in K_2O.

1V) crude decrease in combined Cu, Mo, W values

CHAPTER V

Petrogenesis

5.1 Field Relations

Four types of igneous rocks are distinguished from petrographic and geochemical data. In the field they are distributed such that a zoned complex is formed with granites, the Nashwaak Granite, in the north through quartz diorite to diorite and finally gabbro in the south.

Field data show the relative ages of rock units decreases from the gabbro to the granite. A sharp contact at location C59 between quartz diorite and gabbro with a chilled zone in the latter on the order of a few centimeters in width, indicates it was likely a fairly rigid cooling body i.e. the gabbro had time to cool and solidify somewhat before the onset of magmatism of quartz diorite composition.

Diorite occurs between the gabbro and quartz diorite east of location C59 but is not seen in contact with either. It is assumed that the diorite is syn or post gabbro and pre quartz diorite owing to its relative position in the complex and its consistency with areal chemical trends given in Chapter IV.

In the north at location C10 and C72,quartz diorite can be seen in contact with granite. Here the contact is sharp with a narrow chill zone (2 - 5 cm in width) in the former. Some quartz diorite outcrops have been intruded by granitic dykes of various sizes from 1cm (location C18) to several meters (location C8) in width which modify a pre-existing foliation (see Chapter III and outcrop discussion for C18 in Appendix A). The foliation in these outcrops is variable in orientation and generally more pronounced than in outcrops without these dykes (i.e.C5). The small size of many granite dykes argues for a faily rigid host rock.

5.2 Petrogenic Models

There are three models by which the observed zonation in lithology may have formed:

A) through insitu fractional crystallization of a mafic parent from the margins inward, such as that proposed by Vance (1961);

B) by the multiple emplacement of "crystalline differentiates" "from a mafic magma chamber" beginning with gabbro and ending with granite (Birk, 1978, p.178), with interruption of crystallization along margins by subsequent pulses of more fluid, felsic core magma, such as that proposed by Bateman and Chapple (1979, p.465) for the Tuolumne Intrusive Series;

C) by emplacement at different periods, of comagmatic gabbro, diorite and quartz diorite in the crust, whose latent heat of crystallization caused the partial melting of hosting sediments producing a melt of granitic composition.

Models A and B are similar in that all the rocks are comagmatic. In model B however, the magma chamber is tapped at different times allowing the upward migration of residual, more felsic differentiate as opposed to in situ fractionation as in A.

Field data argues against model A in that there is obviously a time difference between the rocks units, shown by the nature of the contacts where younger units have altered older (i.e.chilled margins, modified foliation orientations).

The trends shown by figures 6 (a) and (b) are fairly consistent with a fractional crystallization model i.e. a comagmatic origin. Trace elements show an overall trend (i.e. positive or negative correlation with index) which in the case of Sr, Ba, and to a lesser extent Rb confirm trends shown by the major cations with which they readily substitute in minerals. A similar gabbro to granite trend is not evident in figure 7 where the granites seem to form a separate field. However this is due to the plots of samples C32 and C45. These, as has been mentioned have anomalously high Rb values which results in an abnormally high Rb : Sr ratio giving a verticle trend appearance to the gabbros, diorites and quartz diorites. A plot of Ba on the ordinate (fig. 8) shows a general increase in Ba: Sr ratio from gabbros to granites.

In figure 9 , the Ca - Na - K ternary plot, the granites diverge perpendicularly from the igneous trend which suggests the operation of processes other than fractional crystallization (Birk, 1978). However remaining rocks do appear to

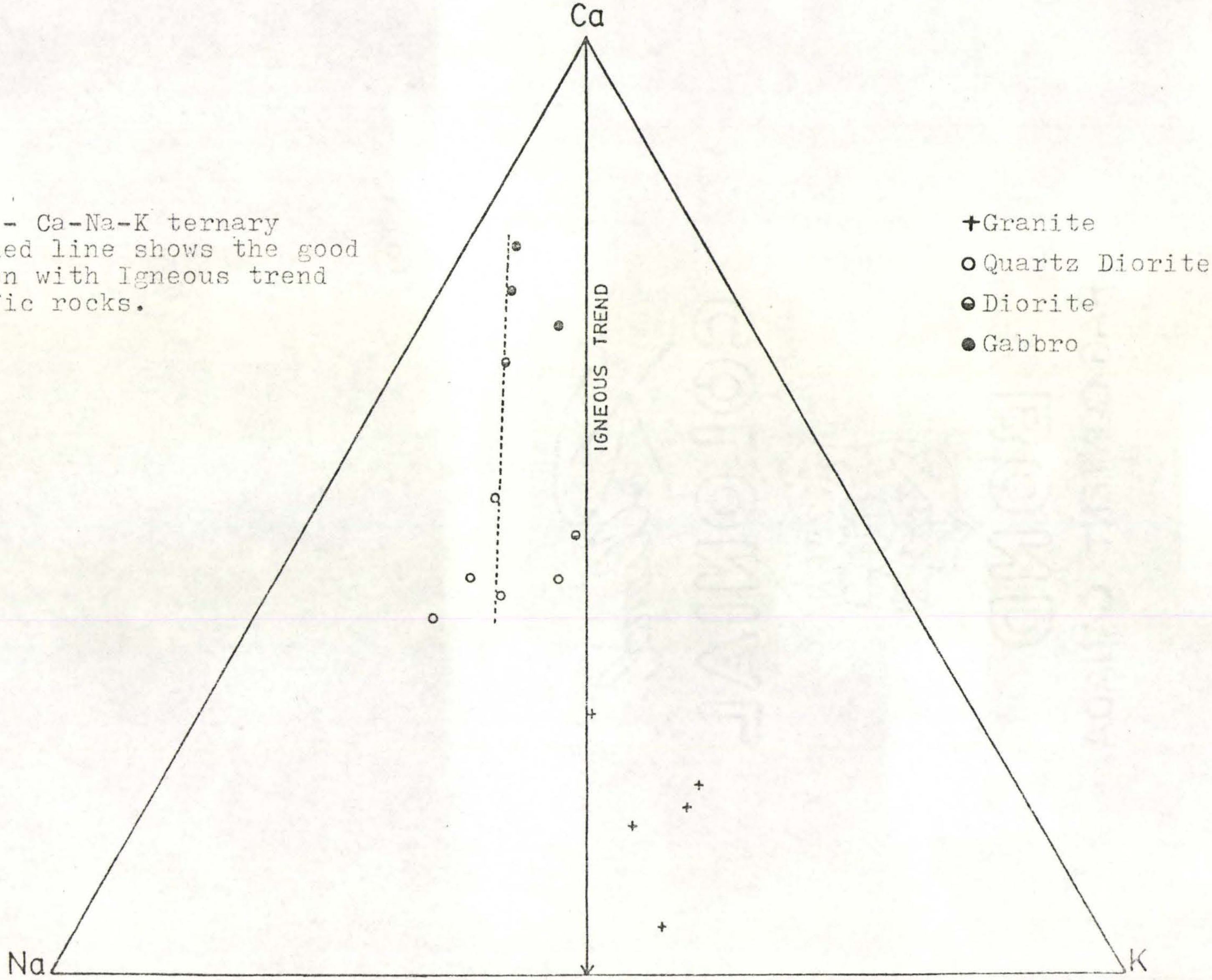


Figure 9 - Ca-Na-K ternary plot. Dashed line shows the good correlation with Igneous trend of the mafic rocks.

form a close parallel correlation with the igneous trend. The exceptions are C72A, C32 and C45 where an enrichment in K is evident in the diagram. C72A is in contact with the younger Nashwaak Granite and thus quite possibly contaminated by K rich fluids from the latter. Also C32 and C45 have been contaminated as indicated by high Rb and K contents. If these samples are ignored, those that remain form a close correlation with the igneous trend. The complete lack of any trend for the granites however makes a similar argument impossible. For them, it cannot be said whether contamination or processes other than fractional crystallization produced the observed data scatter.

Though not conclusive, figure 9, suggests that the Nashwaak Granite is not co-magmatic with the other units. This is supported by the sharp transition from I to S-type character between the more mafic units and the granite respectively.

Model C has the gabbro, diorite and quartz diorite originating as a co-magmatic melts forming a zoned sequence through a process of fractional crystallization (with time variant emplacement i.e. gabbro first etc., as in Model B) while the granites formed from partially melted country rock, in this case sediments of pelitic affinity. If this were the case, it would explain the lithological sequence from gabbro to quartz diorite, their relative age differences, and the apparent change in the origin of granite.

Small xenoliths on the order of 10-15 cm in diameter occur in the northern section of quartz diorite (i.e. locations C5 and C7). The contact nature between the xenoliths and quartz diorite form a continuum between those which are sharp to those which are barely perceptible, the xenoliths appearing as micaceous clots in their host. The latter is evidence that considerable absorption of the xenoliths has occurred. The composition of the xenoliths is similar to that of the meta sediment C4 (a dark, fine grained quartz and mica rich rock). It is feasible to suggest then, that the latent heat of crystallization, given off by the cooling gabbro, diorite and quartz diorite magmas, melted the surrounding country rock producing at high temperatures, a melt of granite composition and the xenoliths represent material that was incompletely assimilated.

The high temperature character of the granite is shown by the abundance of perthite, In their classic study of the system $NaAlSi_3O_8$- $KAlSi_3O_8$- H_2O , Tuttle and Bowen (1958) showed that these perthites (in fact all perthites according to them) represented a high temperature, low pressure feldspar, initially formed as a homogeneous alkali feldspar at temperatures above 660 °C which unmixed when temperature was decreased. Figure 3 attests to the low pressure formation of the granites which plot predominantly in the 500 - 1500 bars P H_2O region. The isobars represent the confining pressures of a water saturated liquid (Carmichael et.al.,1974, p.230, isobaric lines represent experimental data by Tuttle and Bowen, 1958 p.75).

Due to the lack of outcrop and therefore sample density, the exact origin of the rock units is rather speculative at this point. While model C seems to explain both the chemical trends and variations therein, the author emphasizes that based on the information compiled to date, it is impossible to decide with any certainty on one model over the other. It is quite possible that some compromise between models B and C, i.e. fractional crystallization coupled with the syntexis of sediments, formed melts of granite composition.

5.3 Contamination

A K,Rb - metasomatism affects all rock types as shown by both chemistry and mineralogical alterations. The enrichment of the diorites and gabbros in K and Rb has been discussed. This type of contamination is also expressed by the biotization of hornblende in the more mafic phases and the replacement perthite in the granites discussed in Chapter III.

CHAPTER VI

SUMMARY

A zoned plutonic sequence exists in the map area with a marginal hornblende gabbro grading through a diorite, a quartz diorite to a biotite and biotite-muscovite granite (the mid-Devonian Nashwaak Granite) core. While evidence suggests the first three are comagmatic, tapping a common source at different times, the genetic relationship of the granites to this sequence is unknown. Two models seem plausible to explain the granite's origin:

I) as a further fractionated component of the system as a whole (model B in Chaper V) or;

II) by the melting of country rock from the latent heat supplied by the crystallizing gabbro, diorite and quartz diorite magmas intruded into the crust (model C in Chapter V).

While the author prefers the latter explanation, the outcrop density and subsequently the sampling control is much too inadequate to decide with any certainty on one model over the other.

The plutonic rocks, other than the granites have been subjected to a regional metamorphic event as evidenced by a regional foliation and the severe contortion of many small granitic dykes seen in quartz diorite outcrops at locations C17 to C26. However, the metamorphism is of extremely low grade and possibly the result of syn-tectonic emplacement. The granites with the exception of C1 and the above mentioned granite dykes are completely lacking in metamorphic characteristics which suggest that the bulk of the Nashwaak Granite is late syn or post orogenic.

A late stage K, Rb metasomatism is evident in all rock types both mineralogically and chemically. The granites exhibit replacement perthites (with K-feldspar replacing Na-feldspar) while the remaining rocks show biotite replacement of hornblende to variousdegrees. Some of the more mafic rocks (i.e. locations C32 and C45) show anomolous Rb and K values in their chemistry which again attests to a regional K, Rb metasomatism which probably occurred during or shortly after emplacement of the Nashwaak Granite.

APPENDIX

A

All thin sections studied (with the exception of C4 and C18) were point counted (between 500 and 600 counts) in order to give a closer estimate of modal percentages. Since duplicates were available for most, they were stained for alkali feldspar. The thin sections were placed under a fume hood in the vapours of a 52% Hydro-Fluoric acid solution for 10 - 15 seconds, in order to etch the grain surfaces (to help the stain take to the section), then immersed in a super saturated solution of Sodium Cobalta Nitrate for approximately 30 seconds. Staining was positive for the granite samples only, indicating the absence of alkali feldspar in the remaining slides. This aided in the modal analysis.

Plagioclase feldspar compositions were estimated using the Michel - Levy method outlined in Kerr (1977).

Sample Descriptions

A) Granites

Sample C 1:

The rock is orangish, coarse grained, granular, and weakly foliated. For the most part the outcrop is highly weathered. Jointing oriented at 304 / 60W can be seen. Small quartz veins, some containing euhedral Tourmaline crystals occur in the upper or western section of the outcrop.

Quartz - Quartz shows undulatory extinction with highly sutured crystal boundaries. Trains of fluid inclusions and traces of myrmekitic texture with plagioclase can be seen.

Plagioclase Feldspar - Pericline and albite twinning is evident, often coupled with normal concentric zoning. Many grains are highly sericitized thereby obscuring these features. The composition is approximately An_8.

Alkali Feldspar - Microcline is the alkali feldspar present, often replacing plagioclase. Perthite is common.

Biotite - Biotite is pleochroic from a light to deep brown. Chloritic alteration is common and tends to be severe. Opaques and zircon (showing characteristic pleochroic halos) are common inclusion minerals.

Traces of apatite are seen.

Sample C 10:

At location C 10 a contact with quartz diorite can be seen. This contact is sharp and undulatory with a chill zone occurring in the quartz diorite approximately 5 cm in width. C 10 is a non foliated coarse grained, granular rock. Jointing oriented at 310 / 66W occurs.

Quartz - Undulatory extinction and sutured boundaries are shown by quartz. Fluid inclusions are common and traces of myrmekitic texture with plagioclase are seen.

Plagioclase Feldspar - Though albite twinning and some patchy concentric zoning can be seen,the grains have for the most part undergone extensive sericitic alteration masking these features. The composition was therefore hard to determine but ranges between An_{14} and An_{26}.

Alkali Feldspar - Microcline is the alkali feldspar with good Perthite occurring also. In places microcline replaces plagioclase.

Biotite - Pleochroism in biotite is from a pale to deep reddish brown. A few show chloritic alteration but in many the chlorite has simply grown between cleavages thereby parting the biotite grains. Small quartz, euhedral apatite and zircon inclusions are present in many grains.

Sample C72B:

Alkali feldspar megacrysts averaging 0.5 cm in diameter give the rock a sub-porphritic appearance. The remaining minerals are medium grained and granular. C72A a quartz diorite is in contact with C72B at this location.

Quartz - Quartz is medium to coarse grained although fine grained aggregates occur along hairline fractures through the section. It exhibits undulatory extinction and sutured boundaries. Some myrmekitic texture with plagioclase can be seen.

Plagioclase Feldspar - Intense sericitic alteration has masked the presence of zoning or twinning. For this reason

the composition could not be determined.
Alkali Feldspar - Microcline is the alkali feldspar present, with abundant perthite.Replacement of plagioclase is shown by many grains.
Biotite - Biotite is pleochroic from a dull to deep reddish brown. Chloritic alteration with the growth of chlorite between cleavage planes is common.Zircon grains, shown by their dark pleochroic halos, occur with small euhedral apatite as inclusions in the biotite.
Sample C73:

This is a non-foliated, coarse grained, sub-porphritic granite containing K-feldspar megacrysts. Biotite is abundant in the rock (see table 1).
Quartz - Sutured grain boundaries and undulose extinction are shown by quartz. Myrmekitic texture with plagioclase is seen.
Plagioclase Feldspar - Twinning and particularily zoning are indistinct in plagioclase due to intense sericitic alteration. An accurate composition could not be obtained.
Alkali Feldspar - Perthite is abundant. Microcline can be seen in places to replace plagioclase.
Biotite - Biotite is pleochroic from a pale to deep reddish brown. Many crystals are parted along cleavage planes by chlorite,a few show intense chloritic alteration. Apatite is an abundant inclusion mineral with zircon occurring

as well, often as subhedral grains.

Muscovite - Primary muscovite is rare but can be seen intergrown within some biotite aggregates as well as with some plagioclase (where it cross cuts two plagioclase grains thereby distinguishing it from products of plagioclase alteration).

Pyroxene - Small rounded remnants of a highly birefringent colourless pyroxene can be seen associated with a few biotite grains. In some of the larger grains cleavage traces can be seen.

Sample C74:

C74 is similar in all respects to C73, thus will not be dealt with further save to say that a plagioclase composition was obtained which ranged from An_{14} to An_{26}.

Sample C76:

This is a medium grained two mica granite which again, is not foliated.

Quartz - Undulatory extinction and sutured grain boundaries are exhibited by quartz with a few grains containing trains of fluid inclusions.Myrmekitic texture with plagioclase is seen.

Plagioclase Feldspar - Albite twinning occurs with relatively minor amounts of combined carlsbad / albite and pericline twinning. Aften these are combined with normal concentric zoning.The composition ranges between An_{16} and An_{24}.
Sericitic alteration is most severe in the cores of the

zoned crystals and in grains being replaced by microcline.

Alkali Feldspar - Microcline is the alkali feldspar present, with a higher order of grid twinning than that seen in other sections. Perthite is common. Microcline can be seen replacing plagioclase in some areas.

Biotite - Pleochroism is from pale to deep reddish brown. Minute zircon inclusions (seen by their characteristic pleochroic halos) and quartz are found as inclusions while apatite is relatively rare in this section. Only a few grains show chloritic alteration.

Muscovite - Primary muscovite occurs for the most part in aggregates intergrown with biotite. Quartz and small plagioclase laths are common inclusions.

Sample C18:

At this outcrop location a sample of a small (roughly 0.5 to 1.0 cm. in width) granitic dyke was obtained (the host rock is a fine grained mica rich quartz diorite). The dyke is extremely contorted into narrow, ptygmatic folds. It cuts a pre-existing foliation in the host as shown by the warping, in the same direction, of this foliation along the borders of the dyke. The granite is an orangish medium grained quartz rich rock. The following is a mineralogical description of the granitic dyke.

Quartz - Quartz shows undulatory extinction and highly sutured borders with some grains containing fluid inclusions.

Myrmekitic intergrowth with zoned plagioclase can be seen.
Plagioclase Feldspar - Albite and combined carlsbad/albite twins occur often coupled with normal concentric zoning. The composition was found to range from An_{14} to An_{26} .
Alkali Feldspar - Microcline is the alkali feldspar present with Perthite.
Biotite - Pleochroism is from a pale to deep reddish brown (though in some grains the reddish tint is lacking). Some grains have been completely altered to chlorite which show anomolous berlin blue and violet interference colours. (Penninite?)

B) Quartz Diorites

Sample C 5:

C5 is a coarse grained, weakly foliated rock. Small lenticular xenoliths which appear as fine grained quartz-micaceous clots occur in the outcrop.

Quartz - Undulose extinction exists with essentially planer boundaries (though sutured boundaries do exist). Fluid inclusions in some quartz grains give them a cloudy appearance.
Plagioclase Feldspar - Albite, pericline and combined carlsbad/albite twinning occurs with many of the coarser grains showing concentric zoning. None of the grains were cut so that a composition could be determined, though sericitic alteration is minimal.
Biotite - Pleochroism is from a pale to deep reddish brown.

Chloritic alteration is minimal though many grains have been parted along cleavage planes by the growth of chlorite. Apatite and zircon are common inclusions. Biotite is both primary and secondary (replacement of hornblende).

Hornblende - Hornblende is pleochroic from a greenish yellow to a bright green. Colouring often appears patchy due to the presence of twinning. Poikilitic hornblende encloses small quartz,subhedral sphene and apatite grains.

Sphene - Sphene is generally subhedral and is found associated with biotite and/or hornblende aggregates. Quartz inclusions are common and many grains show replacement in the cores by an opague mineral (magnetite?).

Sample C 17:

Outcrop C17 is a medium grained mica rich rock which exhibits a good foliation. It occurs in a zone of relatively abundant outcrop where granitic dykes such as that described in sample C18 are found. Jointing oriented at 308 / 62 W occurs in C17 and is common to many of the outcrops in the immediate vicinity.

Quartz - Quartz grains show various degrees of extinction (some grains are nearly straight) and for the most part sutured boundaries.

Plagioclase Feldspar - Albite, and combined carlsbad/albite twinning are noted, in places combined with a normal concentric zoning. Sericitic alteration is minimal.

Biotite - Biotite is pleochroic from a pale to deep brown. Secondary biotite forms as a replacement of hornblend. Chloritic alteration is minimal. Sphene, apatite, zircon and and opagues are common inclusions.

Hornblende - Pleochroism in hornblende is somewhat variant with some grains pleochroic from a pale greenish yellow to deep bluish green, others from a deep to bluish green . Anhedral to subhedral grains poikilitically enclose sphene, quartz and opagues. Many grains exhibit a simple twin.

Sample C 22 :

Similar to C17 though coarser grained.

Sample C 47 :

Sub-outcrop C47 is a medium grained sub-gneissic quartz rich rock. Owing to its rounded nature, sampling proved to be difficult.

Quartz - Sutured grain boundaries and undulose extinction along with minute fluid inclusions are seen in quartz.

Plagioclase Feldspar - Pericline, combined carlsbad/albite and albite twinning occur, sometimes with concentric (normal) zoning. The plagioclase composition was found to be between An_{12} and An_{26}. Sericitic alteration is minimal.

Biotite - Biotite is pleochroic from a pale to deep brown. Some grains show partial chloritic alteration, especially along cleavage, while others have simply been parted by chlorite crystal growth. Opagues, apatite, zircon, and small anhedral sphene aggregates are found as inclusions in biotite. As no hornblende is seen, the biotite is assumed to be at least predominantly primary.

Sphene - Sphene is found in minor amounts as small anhedral grains associated with biotite.

Sample C 53 (I) :

C53 is a coarse grained crudely foliated granular rock. Both granitic dykes and quartz veins (each on the order of 1.0 cm in width) are found in the outcrops. The granitic dykes are pink medium grained and granular. In section C53 (II) of the outcrops they form a parallel network (lit par lit) oriented 307 / 74 W.

Quartz - Quartz boundaries in this section are planer to undulatory as opposed to strongly sutured. Extinction is fairly straight.

Plagioclase Feldspar - Pericline, combined carlsbad/albite and albite twinning, often along with normal - patchy concentric zoning, occurs in plagioclase. The composition was found to range between An_{20} and An_{28}. Sericitic alteration is moderate, most grains are fairly "fresh".

Biotite - Biotite is pleochroic from a yellow green to a deep olive green. It occurs as primary grains as well as secondary i.e. replacements of hornblende. Chloritic alteration is minimal. Opagues, apatite and very often quartz are found as inclusions in biotite.

Hornblende - Pleochroism is from pale to deep green. Many grains are twinned. Poikilitic hornblende encloses plagioclase, quartz, apatite, and some small anhedral sphene.
Sphene - Though a few subhedral grains occur the majority are small and anhedral. Many show inclusions of an opague mineral (magnetite?).
Sample C 59 (II) :

At location C59 a contact was observed between quartz diorite (C59 (II)) and gabbro (C59 (I)). The contact is sharp and undulatory with a narrow chill zone (approximately 3 cm in width). Rounded or lensoidal bodies of gabbro are seen in the quartz diorite right next to the contact.

C59(II) is a light medium to coarse grained rock which exhibits a well developed foliation.
Quartz - Undulose extinction and planer boundaries are shown by quartz.
Plagioclase Feldspar - Pericline, combined carlsbad/albite and albite twinning are observed in plagioclase, often with concentric zoning. The composition ranged from An_{26} to An_{34} . Sericitic alteration is minimal.
Biotite - Biotite is pleochroic from a pale yellow to olive green. It is largely primary although secondary biotite results from the alteration of some hornblende. Chloritic alteration is minimal with some grains parted along cleavages by the growth of chlorite grains. Quartz and to a lesser

extent opagues, occur as inclusions in biotite.

Hornblende - Hornblende is pleochroic from a light yellow to green. Most grains show simple twinning. Poikilitic hornblende encompasses quartz, some opagues, and apatite.

Sphene - Most of the sphene is associated with hornblende. Much of it is subhedral though many occur as small rounded grains often with opague mineral inclusions.

Sample C 72 A

C72A lies in contact with C72B (granite). The rock is fine to medium grained and shows a moderate foliation. Hairline fractures contain pyrite mineralization.

Quartz - Undulose extinction, sutured boundaries and fluid inclusions characterize the quartz of this section.

Plagioclase Feldspar - Albite and pericline twinning occur in plagioclase. Concentric zoning is relatively rare in the section and none of the grains were suitable for a plagioclase composition estimate. Sericitic alteration varies from minimal to extreme.

Biotite - Severe chloritic alteration masks the pleochroism of biotite in this section. Small euhedral apatite and rarely zircon occur as inclusion minerals.

Small rounded grains of a highly birefrigent, colourless mineral are common. These resemble the pyroxene grains seen in other sections but cleavage traces could not be found, thereby preventing their positive identification.

C) Diorites

Sample C 32:

Outcrop C32 is a dark, medium to coarse grained rock. Quartz veins(approximately 0.5 to 1.0 cm in width) and granitic dykes occur in this outcrop. Although no cross cutting relationships were seen here, at location C43, an outcrop of similar lithology, quartz veining oriented at 310-320 / 70-75 W cuts granitic dykes. At C32 a planer parallel fracture system or "micro" jointing can be seen with similar orientation as the quartz veins in C43.

Quartz - Quartz shows undulose extinction, planer boundaries and in some, trains of fluid inclusions.

Plagioclase Feldspar - Combined carlsbad/albite, pericline and to a lesser extent albite twinning is shown by plagioclase. Normal concentric zoning, often without twinning is common. Plagioclase composition ranges between An_{28} and An_{36}. Sericitic alteration is moderate.

Biotite - Biotite is pleochroic from pale yellow to a deep reddish brown. Most of the biotite appears to be of secondary origin i.e. an alteration product of hornblende. Chloritic alteration is patchy i.e. minimal in some areas, intense in others. In the latter sections, chloritic pseudomorphs of biotite exhibit berlin blue - violet interference colours (i.e. Penninite ?). Euhedral zircon and apatite are common inclusion minerals, opagues occurring in some.

Hornblende - Pleochroism in hornblende is from a greenish yellow to geep green. Simple twinning is evident in many grains. Poikilitic hornblende encompasses plagioclase, apatite, zircon, opagues and in some cases pyroxene remnants. The latter shows faint cleavage but is too small for exact identification of pyroxene type.

Tourmaline (?) - A rose coloured high relief mineral showing faint pleochroism and zoning. It occurs as rounded crystals usually associated with hornblende.

Sample C 50 :

C50 is a dark, medium to coarse grained rock which exhibits a weakly developed foliation.

Quartz - Quartz in the section is interstitial and therefore exhibits planer boundaries. Extinction varies from nearly straight to highly undulose.

Plagioclase Feldspar - Pericline, combined carlsbad/albite and albite twinning are found in plagioclase. Normal concentric zoning is seen in mnay grains usually without twinning. Composition of plagioclase varied between An_{36} and An_{42} . Sericitic alteration is minimal.

Biotite - Biotite is pleochroic from a pale to deep reddish brown. Primary biotite, occurs but is less abundant than that formed through hornblende alteration. Chloritic alteration is minimal with some grains simply parted along cleavage by chlorite crystal growth. Quartz is the predominant inclusion mineral although apatite and opagues can be seen in some grains.

Hornblende - Hornblende is pleochroic from a pale to deep green. Many grains show a simple twinning. Poikilitic hornblende encompasses plagioclase, quartz and less frequently opagues.

D) <u>Gabbros</u>

Sample C 45 :

C45 is a dark coarse grained weakly foliated rock. Quartz veining, 0.5 to 1.0 cm in width, occurs in the outcrops. Dull green zones of intense chloritic / sericitic alteration resembling small "veinlets" (averaging 0.5 cm in width) occur along fracture planes of various orientation. Jointing is seen in area I of C45 (see map) its orientation 320 / 74W.

Quartz - Only a trace of interstitial quartz is found. It shows planer boundaries and straight extinction.

Plagioclase Feldspar - Due to intense sericitic alteration, twinning was seen in only a few grains. In some of the less altered plagioclase, albite and pericline twinning as well as a faint concentric zoning are shown. In these grains the composition was seen to range between An_{46} and An_{50}. Alteration in thin section decreases away from fractures such as those described above. Plagioclase close to these fractures contain high concentrations of very fine grained opague mineral (s?).

Biotite - Biotite is pleochroic from a pale yellow to pale brown colour. It occurs only as an alteration product of hornblende.

Hornblende - Hornblende is pleochroic from a pale to deep blue-green. It occurs for the most part as anhedral, highly altered grains. Those which are less altered are seen to poikilitically encompass apatite, plagioclase and fine grained opagues (magnetite?). Much of the less altered hornblende exhibits simple twinning.

Sphene (?) -Sphene is found in trace amounts as anhedral aggregates associated with biotite and hornblende.

Sample C 59 (I) :

C59 (I) is a dark coarse grained rock with pyrite mineralization occuring along minute fracture planes. Foliation is modified close to the contact with C59 (II), i.e. it is nearly parallel to the contact when close, and almost perpendicular when more distal.

Quartz - Quartz is largely interstitial, with planer boundaries and straight extinction. Some grains contain fluid inclusions.

Plagioclase Feldspar - Albite, pericline and combined carlsbad/albite twinning, often with normal concentric zoning are shown by plagioclase, but these are frequently masked by intense sericitic alteration. Compositional estimates were for this reason unattainable.

Biotite - Biotite is only slightly pleochroic varying from nearly colourless to a pale brown. It occurs solely as an alteration product of hornblende. Chloritic alteration is moderate to severe. Small anhedral sphene aggregates and magnetite, oriented along cleavage planes are common inclusions in biotite.

Hornblende - Anhedral hornblende is pleochroic from light yellow to green. Simple twinning is common. Poikilitic hornblende encloses quartz, apatite and some plagioclase. Minute opague inclusions (Magnetite ?) in parallel alignment along cleavage occurs in many grains.

Sphene - Sphene in the section is predominantly anhedral with many almost entirely altered to opagues.(Magnetite?).

Sample C 66 :

C66 is a dark coarse grained rock which exhibits a strong foliation produced by the alignment of hornblende. Small granitic dykes (averaging 1.0 cm in width) and hairline fractures showing pyrite mineralization can be seen in the outcrop.

Quartz - Quartz occurs interstitially in accessory amounts. Grains show weak undulatory to straight extinction and are inclusion free.

Plagioclase Feldspar - Carlsbad/albite, albite and to a lesser extent pericline twinning occurs in plagioclase often combined with concentric zoning and wavy extinction. The composition ranges from An_{56}- An_{60} . Sericitic alteration is minimal.

Biotite - Pleochroism is from pale yellow to light brown. The biotite in this section is secondary, occurring as an alteration product of hornblende. Chloritic alteration is most pronounced in grains close to hairline fractures. Chlorite growth along cleavage planes warps the grains of some biotite. Apatite, opagues and small anhedral aggregates of sphene are found in inclusions.

Hornblende - Pleochroism is from pale to a deeper green. Simple twinning is common. Subhedral Poikilitic hornblende encloses quartz, plagioclase and apatite (the more abundant). Opague inclusions along cleavage are common.

Sample C 68 :

C68 is a dark, coarse grained well foliated rock.

Quartz - Occurs in accessory amounts interstitially.

Plagioclase Feldspar - Combined carlsbad/albite, albite and pericline twinning occur often with concentric zoning and wavy extinction. Composition of plagioclase ranges between An_{54} and An_{58}. Sericitic alteration is variable from minimal in some grains to intense in others.

Biotite - Biotite is pleochroic from a pale yellow to yellow brown. It occurs only as an alteration product of hornblende. Chloritic alteration is minimal. Opague inclusions are common.

Hornblende - Pleochroism is from pale yellow to green. Simple twinning is common and a few grains exhibit ophitic texture with plagioclase.The grains are predominantly subhedral. Opague inclusions along cleavage are common.

E) Pelitic Hornfels

Sample C 4 :

C4 is metamorphosed sediment which occurs in the granite zone near the crest of the map area's largest hill. The rock is dark and fine grained. The outcrop is very "rusty" with staining taking place along numerous hairline fractures. Discontinuous migmatitic banding (averaging 2.0 to 5.0 cm in width) can be seen. Joints are found in C4 oriented at 304 / 66W.

Quartz - Quartz shows undulatory extinction and planer boundaries with abundant triple junctions. "Bubble trains" of fluid inclusions are pervasive.

Plagioclase Feldspar - Albite and pericline twinning is seen coupled with a faint concentric zoning in some grains. Sericitic alteration is minimal.

Biotite - Biotite is pleochroic from pale yellow to brown. Chloritic alteration is intense, many grains completely altered. Inclusions of zircon are evident through their pleochroic halos in some grains but opague inclusions are far more abundant.

Staurolite - Staurolite is a dull yellow brown in the section. It occurs as xenoblastic grains.

Silliminite - Fibrous trails or rims of silliminte are found associated with staurolite although felted aggregates of silliminite can be seen.

APPENDIX

B

Analytical Procedure - Geochemistry

Samples used for geochemical investigation were prepared by: 1) removing weathered surfaces in order to provide an accurate representation of composition:

2) crushing the rock to a fine powder using a Spec Industries Shatter Box with porcelain rings.

For whole rock analysis the powdered samples were mixed with a lithium metaborate flux in a 6:1 ratio (3.0 grams flux to 0.5 grams of sample). This mixture was fused in Pt crucibles at approximately 1200°C. For the trace element analysis, pressed powder pellets were made according to a procedure outlined by Marchand (1973) (Good, 1981).

Loss on Ignition values for the igneous rocks were below 2% with the lowest values occuring in the granites (where the average was 0.82%).

All but Mo and W analysis was performed at McMaster University using a Philips PW 1450 automatic, sequential, X ray fluorescence spectrometer in the Geology department. Mo and W values were provided by Kidd Creek Mines Ltd.. Mo values were determined with a Direct Current Plasma Spectrometer while W was measured by Neutron Activation.

The precision of XRF results were verified by running standards of known composition with the study samples as well as duplicates of many of the latter. Error in the results were negligible (see Table 8).

Tables 6 and 7 list the CIPW and Meso-normative compositions respectively.

Table 6 CIPW Norms

Sample	Qtz	Cor	Or	Ab	An	Ac	Di	He	En	Fs	Fo	Fa	Mt	Il	Ap
C73	23.72	1.91	28.88	28.06	9.69	-	-	-	3.21	0.86	-	-	2.30	0.92	0.45
C72B	28.47	2.59	25.90	27.55	7.77	-	-	-	3.98	0.43	-	-	2.19	0.79	0.32
C76	30.51	2.08	23.77	32.81	6.67	-	-	-	2.21	-	-	-	0.29	0.34	0.28
C74	23.31	1.88	19.51	32.44	12.69	-	-	-	4.85	1.28	-	-	2.39	1.06	0.59
C1	28.91	-	30.65	32.94	-	3.22	1.93	-	0.95	-	-	-	-	0.05	0.11
C72A	22.84	2.46	13.34	27.19	19.39	-	-	-	8.30	1.76	-	-	2.72	1.50	0.49
C5	5.63	-	11.83	43.86	19.38	-	3.75	0.76	8.64	1.75	-	-	2.55	1.32	0.54
C17	11.32	-	9.78	34.85	26.03	-	1.91	0.41	9.20	1.95	-	-	2.63	1.40	0.51
C47	20.30	0.60	9.22	41.44	19.01	-	-	-	5.19	0.69	-	-	2.28	0.94	0.34
C53	15.59	-	12.77	37.79	21.41	-	0.15	0.02	7.66	0.79	-	-	2.38	1.08	0.36
C32	3.42	0.79	16.73	30.70	26.65	-	-	-	12.51	3.74	-	-	2.83	1.68	0.94
C50	3.60	-	6.60	29.25	35.24	-	4.75	1.24	11.28	2.96	-	-	2.91	1.78	0.38
C45	-	-	9.50	22.79	37.43	-	7.01	1.77	1.04	0.26	11.30	2.85	3.29	2.29	0.46
C66	-	-	4.33	24.86	38.80	-	5.95	1.94	9.37	3.05	3.32	1.08	3.74	2.85	0.70
C68	-	-	3.34	21.54	44.78	-	5.63	1.47	3.68	0.96	9.90	2.58	3.41	2.44	0.27

Table 7 Meso-norms

Sample	Qtz	Cor	Or	Ab	An	Act	Ed	Ri	Bi	Ol	Hy	Mt	Tn	Ap
C73	26.11	2.82	23.95	28.04	7.32	-	-	-	7.63	-	-	2.28	1.39	0.44
C72B	31.05	3.40	20.95	27.44	5.77	-	-	-	7.70	-	-	2.18	1.18	0.32
C76	31.82	2.44	21.86	32.78	5.81	-	-	-	2.97	-	-	0.98	0.51	0.27
C74	26.80	2.94	12.67	32.30	9.97	-	-	-	10.78	-	-	2.37	1.58	0.59
C1	31.83	-	28.93	32.87	-	-	-	0.12	2.54	-	-	-	0.23	0.11
C72A	28.50	3.95	2.72	27.02	15.55	-	-	-	16.84	-	-	2.70	2.24	0.49
C5	11.28	-	-	43.67	19.21	1.39	-	-	18.84	-	-	2.53	1.96	0.54
C17	15.89	0.23	-	34.64	25.29	-	-	-	15.55	-	3.21	2.61	2.08	0.50
C47	23.70	1.57	2.89	41.27	16.54	-	-	-	10.01	-	-	2.27	1.40	0.36
C53	20.26	0.98	4.08	37.67	18.87	-	-	-	13.82	-	-	2.37	1.60	0.35
C32	12.25	2.42	0.37	30.52	22.31	-	-	-	25.90	-	-	2.81	2.49	0.94
C50	5.52	-	-	28.96	34.96	4.55	-	-	10.54	-	9.58	2.88	2.64	0.38
C45	-	-	-	20.36	37.04	1.25	7.0	-	15.01	-	12.24	3.26	3.40	0.46
C66	-	-	-	23.19	38.37	-	4.29	-	6.81	2.13	16.62	3.68	4.22	0.69
C68	-	-	-	19.96	44.27	-	4.36	-	5.26	10.96	7.91	3.38	3.63	0.27

Table 8 XRF Results for Duplicated Samples (Major Oxides in weight percent, Trace Elements in ppm).

	C72A	C72A1	C72B	C72B1	C73	C731	C76	C761
SiO_2	63.74	63.66	70.06	69.69	67.89	67.93	73.02	73.15
Al_2O_3	16.53	16.48	14.80	14.82	15.50	15.38	14.59	14.68
Fe_2O_3	5.97	5.96	3.86	3.85	4.45	4.38	2.06	2.09
MgO	2.96	2.88	1.42	1.53	1.14	1.26	0.80	0.84
CaO	4.15	4.13	1.74	1.75	2.20	2.11	1.50	1.46
Na_2O	2.98	3.29	3.02	3.22	3.09	3.34	3.62	3.39
K_2O	2.22	2.15	4.31	4.37	4.81	4.70	3.98	3.97
TiO_2	1.06	1.06	0.56	0.56	0.66	0.62	0.24	0.24
MnO	0.16	0.16	0.08	0.06	0.05	0.06	0.06	0.06
P_2O_5	0.22	0.22	0.15	0.15	0.21	0.21	0.13	0.12
Rb	147	149	124	122	160	157	210	206
Sr	318	318	277	275	206	208	109	106
Ba	315	340	668	603	1321	1400	303	306
Zr	250	231	296	288	380	394	152	151
Cr	34	59	30	13	34	40	25	44
Co	18	21	9	8	16	12	0	0
Pb	26	25	31	33	38	40	21	25
Cu	18	20	14	3	3	0	4	6
Zn	127	128	50	44	67	66	42	45

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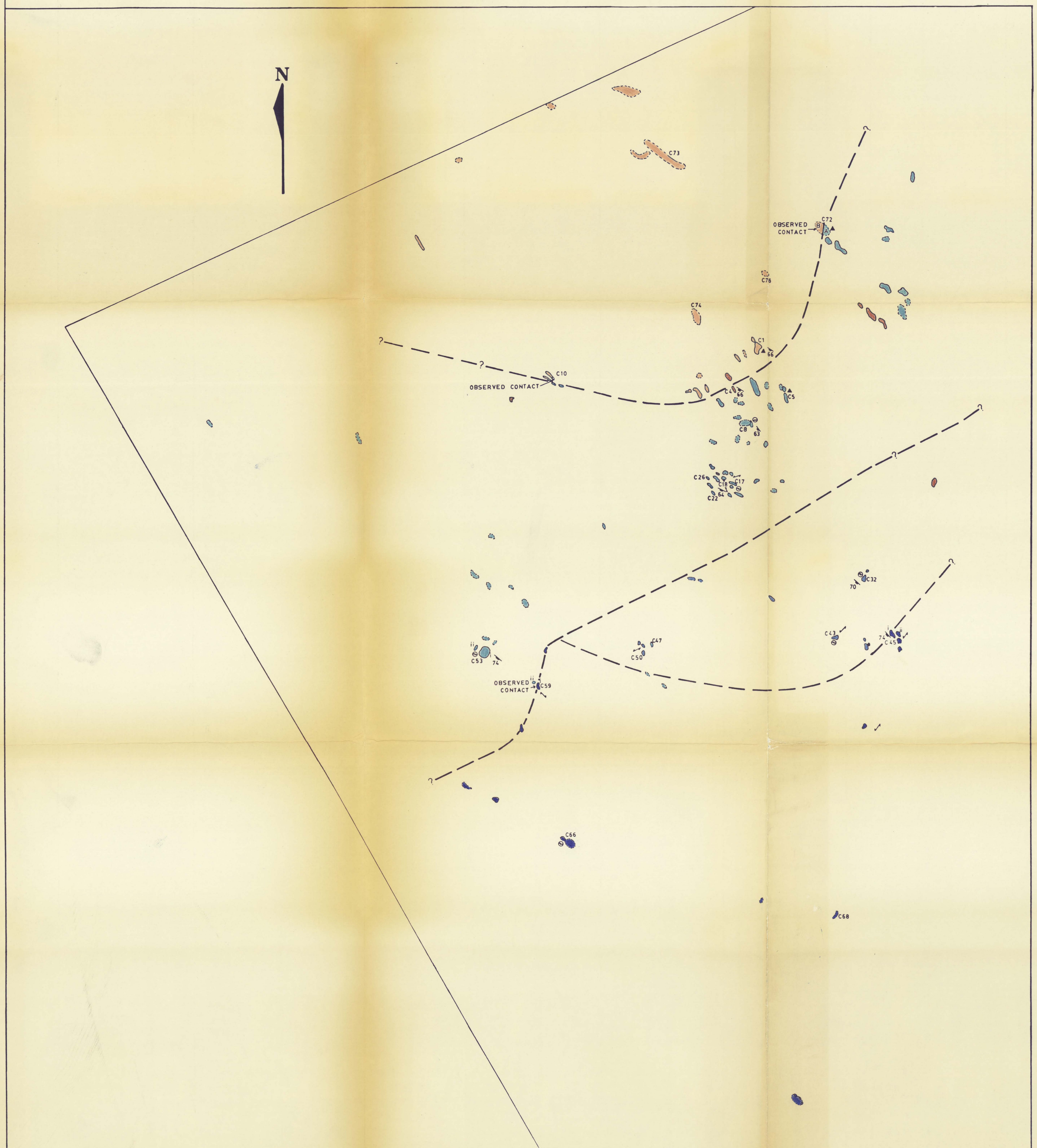
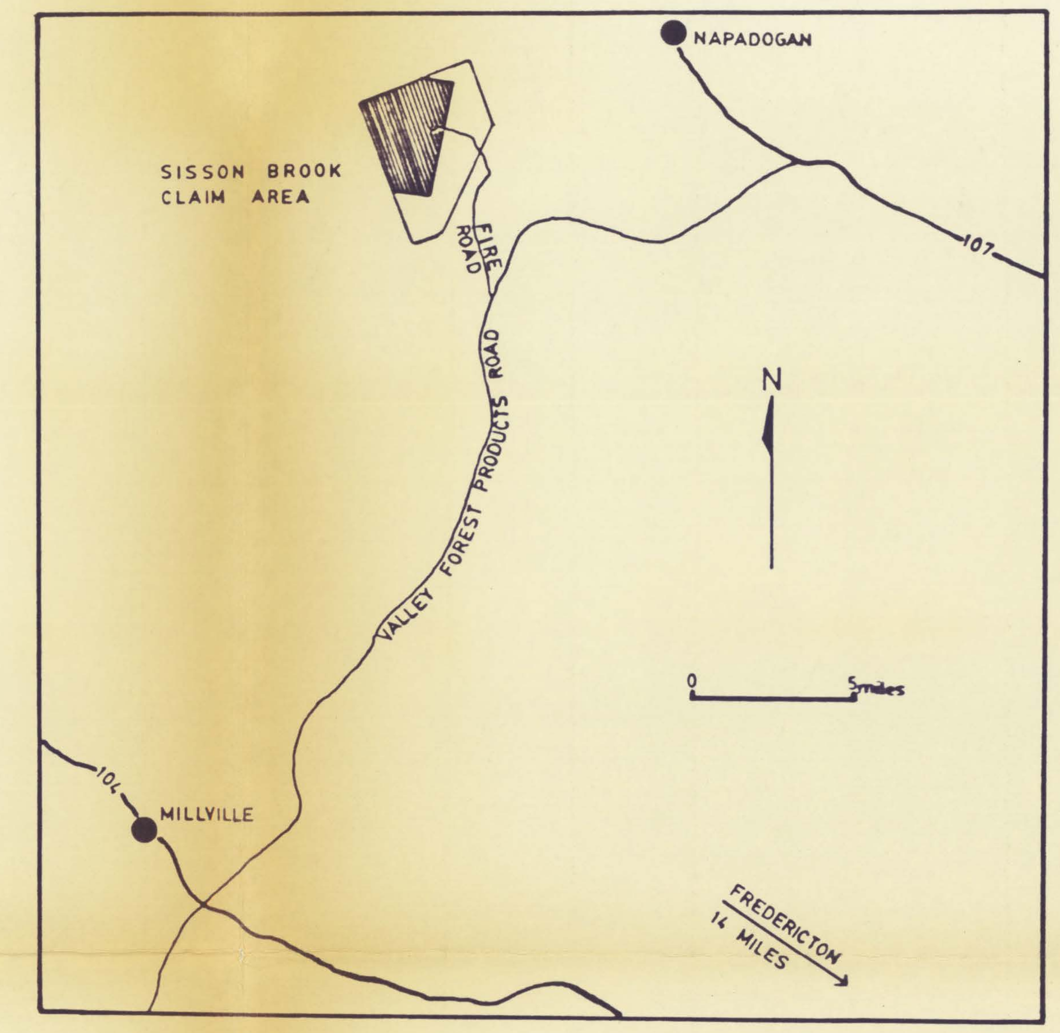
GEOLOGY: SISSON BROOK CLAIMS





LEGEND

NASHWAAK GRANITE

QUARTZ DIORITE

DIORITE

HORNBLENDE GABBRO

PELITIC HORNFELS

OUTCROP AND REFERENCE NUMBER

SUB OUTCROP AND REFERENCE NUMBER

GRANITE DYKES

XENOLITHS

JOINTS

FOLIATION

ESTIMATED GEOLOGICAL CONTACT

APPROXIMATE PROPERTY BOUNDARY

0 500m

SCALE 1:5000

P. J. LOUGHEED 1982