# THE PETROLOGY AND STRUCTURAL RELATIONS OF METAGABBROS FROM THE WESTERN GRENVILLE PROVINCE, CANADA

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#### ABSTRACT

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Deformation in the Grenville province culminated at 1.15-1.0 Ga. and possibly extended back to 1.3 Ga., making it the youngest structural unit within the Canadian shield. Recent work in the Central Gneiss Belt (CGB) of SW Grenville province has outlined a number of domains of different structural, litholgical and metamorphic character. These discrete crustal blocks are bounded by broad, ductile shear zones which commonly include tectonic fragments of gabbroic and anorthositic material in various stages of strain and degradation of the primary fabric. The shear zones are the lower crustal reflection of ductile thrusting during the culmination of the Grenvillian orogeny and contain kinematic indicators that consistently imply northwest-directed transport.

The metagabbros have a continental basaltic signature and were probably emplaced in an extensional setting at around 1.2 Ga. They then underwent a complex and multi-stage textural evolution controlled by reaction kinetics. Early reactions were diffusion-controlled and involved the subsolidus formation of garnet-bearing coronas that separated plagioclase from olivine and opaque oxides. This probably occurred during cooling from magmatic temperatures at depths of around 35 km in the crust where calcic plagioclase was unstable and became more sodic, thus liberating Ca for corona growth and exsolving excess Al as spinel. Olivine coronas have been modelled in terms of steady state diffusion in order to estimate relative component mobilities during corona growth. The following results were obtained: restricted mobility of aluminium and to a lesser extent Si, was rate-controlling during corona growth; uphill Ca-diffusion may have been important; Mg and Fe have similar mobility with Mg at least as mobile as Ca and probably more so. Metastable under the changing regional metamorphic conditions, the delicate coronas were susceptible to further P-T-aH20 constrained reactions which eventually led to the formation of two pyroxene granulites or garnet amphibolites.

The host rocks equilibrated under granulite and upper amphibolite facies conditions at 1.16 to 1.03 Ga. and the P,T estimates range from 8-10 Kbars and  $700-750^{\circ}$ C, with no significant differences between the various lithotectonic domains. This implies that provided the shear zones were sites for large crustal displacements, the cation distributions employed in the geothermobarometers must have been reset by continuous reactions after thrusting, and further that the fluid activity controlled whether granulite or upper amphibolite facies assemblages became stable on both local and regional scales.

Relict high pressure assemblages are present in garnet peridotites and sapphirine-bearing mafic boudins collected from the ductile shear zones and as in the coronite metagabbros, unfavourable kinetics were again responsible for the preservation of the discontinuous reaction textures. In the sapphirine-bearing meta-eclogite the primary mineralogy involving high-Al clinopyroxene, pyrope-rich garnet and kyanite<u>+</u>plagioclase, records pressures of around 14-16 Kbars whereas subsequent decompression products including sapphirine, corundum, spinel, plagioclase, quartz and orthopyroxene, equilibrated at around 11-12 Kbars. As it is unlikely that the host rocks went through such a high pressure event, it is proposed that the shear zones were active and incorporated material fron depths of at least 50-55 Km in the thickened Grenvillian crust during the culmination of the Grenvillian orogeny.

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### CHAPTER I

### INTRODUCTION

This thesis examines the petrology and structural relations of metagabbroic rocks from the Central Gneiss Belt (CGB) of southwest Grenville province. The metagabbros crop out as discrete clusters within the structural domains and marginal shear zones that make up the CGB (Fig. 1.1). They display a complicated textural evolution which can be related to the tectonic history both before and during the culmination of the Grenvillian orogeny. In doing so reaction mechanisms are investigated and evidence for kinetic controls on the preservation of disequilibrium assemblages during metamorphism assessed.

The next Chapter discusses the general geology of the western Grenville province while Chapter 3 focusses on the CGB itself and outlines the field relations of metagabbroic rocks. Together these provide the tectonic framework for documenting the reaction history of metagabbros (Chapter 6) and for evaluating metamorphic conditions in the host rocks (Chapter 5).

Chapter 4 describes the whole rock geochemistry of the metagabbros and anorthosites with the aim of determining: a) if individual clusters of gabbroic rocks are all part of the same gabbroic suite; b) if coronite metagabbros are genetically related to the anorthosite; c) the likely tectonic setting of the magmatism; d) the possible influence of bulk composition on later products from subsolidus reactions.

The enclosing host rocks are the topic of Chapter 5 and here quantitative P,T estimates are used to constrain the likely peak metamorphic conditions and a possible P-T path for the latter part of the Grenvillian orogeny. This can be used to assess whether the metamorphism reflects additional heat from either tectonic thickening, magmatic accretion or a combination of these two processes. The host rocks contain assemblages from both the granulite and upper amphibolite facies and the importance of varying fluid activity as a possible control on this is also discussed.

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Chapter 6 outlines the complicated reaction history in metagabbros and investigates how the changing external controls, including P,T and fluid composition, affect the reaction products that develop. It evaluates how this relates to the overall tectonic history and stresses the important deductions that can be made from disequilibrium textures.

In Chapter 7 a case study of internal kinetic controls on the initial corona-forming reactions is presented. It discusses likely reaction mechanisms and attempts to put semi-quatitative estimates on relative component mobilities and outlines how the kinetics change from diffusionto interface-controlled in the subsequent metamorphic evolution.

Chapter 8 continues the kinetic theme by considering sapphirinebearing lithologies. These have been found as boudins from tectonite zones within the CGB and again the textures document a complicated reaction history that was probably brought about by thrusting during the culmination of the Grenvillian orogeny. The likely tectonic inferences from the different assemblages are discussed.

The final Chapter presents a short synopsis of the data presented in this thesis and is followed by a list of publications to which reference is made in the text. Sample descriptions, grid references, analytical techniques, thermodynamic abbreviations and geochemical data are presented in the appendices.

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### CHAPTER II

### **REGIONAL SYNTHESIS**

#### 2.1 INTRODUCTION

The Grenville province is the southernmost and youngest structural unit in the Canadian Shield. It is approximately 400 km wide and continues from Georgian Bay on Lake Huron northeastward to Labrador in Atlantic Canada, a distance of some 1900 km. It is the type locality for the Grenvillian orogenic cycle (ca. 1.3 to 1.0 Ga.) which culminated at 1.15 to 1.0 Ga. The Grenville orogen is recognised in northwest Europe: in the Moines of western Scotland and beyond, in the Sveconorwegian province of Scandinavia. It also extends southwestward from the Canadian shield and Adirondack Highlands in New York State, beneath the Phanerozoic cover of the southern United States to expose Grenvillian equivalents in the southwest U.S.A and Mexico. Wynne-Edwards (1972) divided the province into seven subprovinces (Fig. 2.1) on the basis of structural and metamorphic style. This chapter is a summary of recent work in the southwest part of the province, mainly by A. Davidson and co-workers, and outlines the tectonic framework for subsequent chapters. Readers are directed to reviews by Wardle et al. (1986) and Rivers (1983) for recent research in section Of the Grenville Province. A summary of the northeast geochronological data is presented in Table 2.1.

#### 2.1.1 THE GRENVILLE FRONT AND GRENVILLE FRONT TECTONIC ZONE (GFTZ)

The Grenville Front marks the northern limit of the province. In the southwest this is reflected in truncation, transposition and cataclasis of the generally east-west structures in the adjacent foreland of Southern and Superior Provinces, and the resetting of K-Ar isotopic clocks close to Superior Province is an Archaean granite-greenstone terrane, the front. is a predominantly supracrustal, early whereas Southern Province Proteozoic terrane which is either unmetamorphosed (the Cobalt embayment). metamorphosed up to lower amphibolite facies, and deformed by Penokean or folding (ca. 1.85 Ga.). In the far west, southwest of Sudbury, Grenvillian rocks are juxtaposed against a mid-Proterozoic magmatic complex in the

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# TABLE 2.1: Geochronology across the Grenville Belt

FORELAND & GRENVILLE FRONT	CENTRAL GNEISS BELT	CENTRAL METASEDIMENTARY BELT	ADIRONDACKS	LABRADOR, NE GRENVILLE
Huronian > 2.15 Ga. from post-Huronian Nippissing	Major Plutonic Rocks: Britt, 1.46 - 1.36 Ga.	Grenville Supergroup < 1.3 Ga. (Bell &	Marcy anorthosite 1.29 Ga. (Ashwal & Wooden, 1983)	Magmatism 1.71-1.63 Ga.
diabase, Van Schmus(1965) Penokean folding 1.85 Ga.	Parry Sound, 1.42 Ga. Whitestone Anorthosite	Blenkinsop, 1980).	-intruded by coronite metagabbro body	Pegmatites, ca. 1.5 Ga.
affects Huronian Supergp.	in PSSZ, ca 1.35 Ga. Algonquin, 1.46 Ga.	Basic volcanics, ca. 1.29 Ga., (Silver &	-high level intrusion (Valley & O´Neil 1982)	Michael Gabbros 1.43 Ga. -inferred to be rift
Granitic plutonism and magmatism 1.75-1.70 Ga.	(Van Bremen et al.,1986) Muskoka, 1.47 Ga.	Lumbers, 1966)	Metavolcanics in Adiron-	related magmatism.
in the Killarney area - affected by Killarnean orogeny, ca. 1.55 Ga.,	(Krogh et al., 1967)	Elzevirian tonalitic to granitic plutonism,	dack lowlands ca. 1.20 Ga.	Metamorphism in Southern Labrador, ca. 1.03 Ga.
Stockwell (1982). Mamgmatism 1.5-1.34Ga:	Parry Sound granulite facies metamorohism.	ca. 1.23 Ga.	Granulite facies meta- morphism ca. 1.10-1.02 Ga.	Metamorphism in Northern Labrador, ca. 0.97 Ga.
Both have equivalents in mid-Proterozoic, mid- continental North	ca. 1.16 Ga. (Van Bremen et al., 1986).	Syn- to late-tectonic intrusives, including small plutons of	(U-Pb, Silver 1969). or 1.095 Ga. Sm-Nd (Basu & Pettingill, 1983).	(Schärer et al., 1986)
American magmatism.	Syntectonic pegmatite ca. 1.16 - 1.12 Ga.	younger gabbro, syenite and granitic		
Deformation 1.7 - 1.65 Ga Mid-Proterozoic orogeny	(Van Bremen et al.,1986)	compositions, ca. 1.15 - 1.0 Ga.		
widespread in southern Great Lakes area to west,	Algonquin granulite facies metamorphism,	(Stockwell, 1982)		
north of proposed contin- uation of the Grenville province	ca. 1.03 Ga. (Van Bremen et al., 1986).	Shearing in CMBBZ, ca. 1.07 - 1.03 Ga. Late pegmatites and		
Plutonism in GFTZ 1.74 and 1.55 Ga. (Krogh & Wardle, 1984).	1	shearing ca. 0.99 Ga.		
Sudbury diabase dykes ca. 1.25 Ga., possible deformed equivalents				

and a sublimation of the second data and the second

in the GFTZ.

FIGURE 2.1: Subdivisions of the Grenville province after Wynne-Edwards (1972). Area and line of section for Figures 2.2 and 2.3 are indicated; K - Killarney area.



Killarney area (Davidson, 1986b), located on Figure 2.1. The magmatism is high level and includes granitic and volcanic rocks emplaced at 1.75-1.70 Ga. and 1.5-1.34 Ga. These are probably equivalent to the two independant packages of mid-Proterozoic magmatism recognised by Bickford et al. (1986) in the core of North America (Table 2.1). These were deformed before the emplacement of the undeformed Sudbury diabase dykes (Table 2.1) which probably have tectonised equivalents in the Grenville Front Tectonic Zone, implying that their intrusion predates the deformation along the Grenville Front. There is a very abrupt transition from dominantly brittle deformation immediately north of the front, to progressively more ductile deformation southeastwards, into the Grenville Front Tectonic Zone (GFTZ). The Front is marked by high-angle reverse faults and thrusts although in places, its precise location is debatable. The rocks have a cataclastic appearance and include zones of mylonite, ultramylonite and locally pseudotachylite. The GFTZ is characterised by a strong NE-SW strike, telescoped metamorphic isograds and a well-developed, southeasterlyplunging stretching lineation. Kinematic indicators consistently imply northwest-directed transport of Grenvillian rocks onto the foreland. The southeast limit of the GFTZ is ill-defined, but marks the change from Front-parallel northeasterly trends to more variable orientations in the Central Gneiss Belt to the southeast.

A seismic reflection study across the Ottawa-Bonnechère graben, by the COCRUST project incorporated the Grenville Front and Central Metasedimentary Belt boundary zone (CMBBZ) but picked up no mid-crustal discontinuity, although a strong velocity gradient is present between Superior and Grenvillian rocks (Mereu et al. 1986). The gradient is consistent with approximately 20 km of uplift on the Grenville side. In addition the Grenville Front is observed to extend down to a depressed Moho, representing 5 Km of thickened crust in the vicinity of the front, whereas the crust on either side is of normal thickness (35 to 40 km). This interpretation is consistent with a negative Bouguer gravity anomaly along the Grenville Front. Thus at least some of the ductile thrusts and shear zones may continue down to moho depths.

South of the Grenville Front tectonic zone (GFTZ), deeper levels of more ductile deformation are represented by rocks of the Central Gneiss Belt (CGB). This is truncated in the south by the emplacement of marbles and metavolcanics belonging to the Central Metasedimentary Belt (CMB). The boundary between the two is tectonic and the Central Metasedimentary Belt

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Boundary Zone (CMBBZ) comprises intensely sheared and flattened rocks, including tectonic breccias of marble and quartzo-feldspathic gneissic tectonites with a strong southeast-plunging stretching lineation. It also contains trains of anorthositic and gabbroic material and at least one large anorthosite body. Deformation has been dated at 1070 to 990 Ma (Table 2.1) and it is interpreted as an imbrication zone formed by relatively low angle thrusting, for which kinematic indicators imply northwest-directed transport (Hanmer & Ciesielski, 1984), although the amount of displacement is unknown. The CHB may be wholly allochthonous to the Central Gneiss Belt or alternatively, the boundary zone may represent a reworked and deformed unconformity of supracrustal successions on a gneissic basement.

#### 2.1.2 THE CENTRAL METASEDIMENTARY BELT

The supracrustal succession making up the Central Metasedimentary Belt is known as the Grenville Supergroup. It probably reaches a thickness of around 15 km but the stratigraphy is poorly understood. The magmatism has been dated at 1.3 to 1.2 Ga and predated the Grenvillian deformational events (Table 2.1), but occurred within the Grenvillian orogenic cycle (ca. 1.3 to 1.0 Ga.). A recent review is presented in Davidson (1986a). In summary it has been subdivided into several terranes, based on marble associations and inferred stratigraphy, and the metamorphic grade is dominantly middle to upper amphibolite facies, although in one terrane upper greenschist to lower amphibolite facies assemblages are preserved. It is not yet known whether these terranes represent facies variations or different stratigraphic levels because interpretation is complicated by deformation and numerous dislocation zones that indicate considerable crustal shortening. The stratigraphy is best known in the Elzevir terrane, in places only metamorphosed to greenschist facies. Here the sediments and volcanoclastics suggest deposition in a shelf or shelf-slope environment. In addition it has been suggested by Holm et al. (1983) and others, that the 1.29 Ga. tholeiitic to calc-alkaline volcanic rocks (Table 2.1) have ocean floor and island arc affinities. This was followed by the intrusion of subduction-related tonalitic to granitic plutons at 1.25 Ga. In this interpretation the associated Grenvillian Supergroup sediments may have formed in a shallow inter-arc basin.

The metamorphic grade in the CMB increases to the northwest, towards

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the CMBBZ, and to the southeast where relatively low pressure cordieritehypersthene granulites occur along the Frontenac axis, near the border with the U.S.A. (Fig. 2.1, 2.4). Further southeast the grade decreases to upper amphibolite in the Adirondack Lowlands of New York State, before encountering the Central Granulite Terrane (CGT), to the east and southeast. Metamorphic conditions in the Adirondack Highlands (CGT) were estimated by Bohlen et al. (1985) at 750-800°C and 7.5-8.0 Kbars. The high temperatures are either the result of magmatic accretion, or crustal thickening during thrusting at around 1.1 Ga (Table 2.1). However, it was not caused by the intrusion of the Marcy anorthosite (ca. 1.29 Ga.; Ashwal & Wooden, 1983) because Valley & O'Neill (1982) and Valley (1985) presented evidence, on the basis of low  $\delta^{18}$ O values in wollastonite skarns adjacent to the anorthosite, that it was a shallow level intrusion. Thus metamorphism if related to magmatism, must reflect a presently unexposed phase of syntectonic plutonism.

In New York State, the boundary between the CGT and CMB is known as the Carthage-Colton Mylonite Zone. It is up to 7 km wide and contains intensely sheared rocks that extend northwards, as the Chibougamau-Gatineau lineament, into Quebec. It has a well-developed down-dip stretching lineation that plunges to the northwest, in contrast to the ubiquitous southeasterly down-dip lineation in the boundary shear Zones to the north. However tectonite fabrics still suggest northwest-directed transport, with top-side down transport of granulite facies rocks onto the amphibolite facies Adirondack Lowlands. Metamorphic conditions in the Adirondack Lowlands have been estimated at 6.5-7.0 Kbars and 650°C, increasing to 700-750°C next to the Carthage-Colton Mylonite Zone (Bohlen et al., 1985).

## 2.2 THE CENTRAL GNEISS BELT

The Geological Survey of Canada has been mapping at reconnaissance scale in the western part of the Central Gneiss Belt for several years (Davidson & Morgan, 1981, Davidson et al., 1982, Culshaw et al., 1983, Davidson et al. 1986). This region has been divided into various domains and subdomains on the basis of differences in structure. lithology and metamorphic grade (Fig. 2.2). These discrete crustal blocks or slices are enveloped by continuous tracts of highly strained and flattened rocks,

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FIGURE 2.2: Subdivisions of the Central Gneiss Belt (CGB) in western Grenville province.



FIGURE 2.3: a - Schematic tectonic cross-section (after Davidson, 1984); b - Proposed stacking sequence in the CGB.



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locally including mylonites and blastomylonites. They are commonly well banded and strongly attenuated (Plate 2.1a) and referred to as flaggy tectonites or "straight gneisses" (Davidson et al. 1982). These tectonite zones either truncate or transpose structures in the adjacent domains or subdomains. There is a pervasive southeasterly-dipping stretching lineation throughout the belt which becomes extremely uniform in the boundary zones where later deformation was concentrated. Kinematic indicators, such as rolled feldspar porphyroclasts (Plate 2.1b), C-S fabrics, rotated boudins and climbing pegmatites (Davidson, 1984) have been used to infer transport in a consistently northwesterly direction along the boundary shear zones. These zones commonly include lenses of anorthositic gneiss (Plate 2.1c), trains of which can be traced for many kilometres along structural horizons.

The domains are interpreted as thrust slices and Figure 2.3 is a cartoon of the probable emplacement sequence namely: early thrusting of Parry Sound domain (deck 2) onto the gneissic basement, comprising Britt and Algonquin domains along with Go Home and Rosseau subdomains (deck 1), followed by the emplacement of the rest of Muskoka (deck 3), including the migmatitic gneiss lobes of Seguin and Moon River. Absolute displacements have not been determined, but may have been large where granulite facies rocks are emplaced onto amphibolite facies basement. Deformation ages from syntectonic pegmatites in the Parry Sound shear zone range from 1.15 to 1.12 Ga. (Table 2.1), whereas shearing in the Central Metasedimentary boundary zone has been dated at 1.07 to 1.03 Ga. This suggests that relative displacement occurred over at least 100 Ma., with major dislocation zones apparently younger towards the southeast.

The domains include large tracts of granulite and amphibolite facies gneisses and migmatites (Fig. 2.4). Peak P-T conditions have been estimated at  $800^{\circ}$ C and 10-11 kb by Anovitz (1986) and these compare favourably, although slightly higher than the estimates presented in Chapter 5. The rocks are thoroughly deformed and generally the protolith cannot be identified. As a result only units of unequivocal origin have been designated as meta-plutonic or meta-sedimentary. Rocks of undoubted sedimentary origin include aluminosilicate and graphite-bearing pelites or semi-pelites, quartzites, marbles and calc-silicates. Granitic metaplutonic rocks are recognised by their relict feldspar augen. commonly enveloped by attenuated quartz ribbons, which can be traced into the deformed, migmatitic equivalents. Basic rocks such as the coronite

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## PLATE 2.1

A: Well banded "straight gneiss" from Parry Sound shear zone (PSSZ).

1.1

Street a

See. 5.

- B: Rotated felspar porphyroclast in mylonite derived from the Whitestone anorthosite, Parry Sound shear zone (PSSZ); kinematic sense is indicated and implies NW-directed transport.
  - C: Tectonic inclusions of anorthosite in flattened mignatitic gneisses from the boundry shear zone between Rosseau and Moon River subdomains.

D: Transposed mylonitic fabric in the Parry Sound shear zone.



FIGURE 2.4: Distribution of granulite facies rocks in western Grenville province (after Schau et al., 1986). NB - North Bay; PS - Parry Sound; F -Frontenac axis.



metagabbros, may retain a relict ophitic texture.

Major granitic plutonism in the CGB has been dated at 1.5 to 1.3 Ga. (Table 2.1) and may represent the deformed equivalents of the later phase of mid-continent magmatism described in central North America, north of the proposed extension of the Grenville province. The granulite facies metamorphism in Parry Sound domain has been dated from zircon overgrowths (Van Breemen et al., 1986) at 1.16 Ga. In Algonquin domain the metamorphism appears to be approximately 100 Ma later. Before discussing the tectonic implications of these observations the major features of each of the subdomains will be described.

#### 2.2.1 BRITT DOMAIN

Britt domain is composed of amphibolite facies pink and grey migmatitic gneisses that enclose large granitoid bodies of orthogneisses which form sheets folded about southeast-plunging axes. The structures in Britt are truncated by the Parry Sound shear zone (Fig. 2.2). Internal shear zones just north of Parry Sound domain, near the town of Arnstein (S in Fig. 2.2), contain kyanite-sapphirine assemblages in mafic boudins of "pseudoeclogitic" material (Davidson et al., 1982). They are in a matrix of highly strained migmatitic gneisses and have plagioclase rims separating clinopyroxne from garnet. Samples of this material (81DM-155E,F & G), provided by A. Davidson, are discussed in Chapter 8.

#### 2.2.2 PARRY SOUND DOMAIN

This is characterised by compositionally distinctive mafic to intermediate pyroxene-bearing granulites enclosing minor marble and hypersthene, sillimanite-bearing pelitic gneisses. It is bounded on all sides by tectonite zones (Fig. 2.2). The internal gneissic trends are generally northerly and steeply inclined to the east. Recognisable plutonic rocks range from gabbroic to granodioritic in composition but so far, no olivine-bearing coronite metagabbros (or their likely metamorphosed equivalents) have been identified.

The boundary zone between Parry Sound and Britt domain is known as the Parry Sound shear zone (PSSZ) and is 1-3 km wide (Davidson, 1984). It

is characterised by finely banded gneisses (Plate 2.1a), mylonites, sheath folds, boudinaged pegmatites, detached and refolded folds, transposition of mylonitic fabrics (Plate 2.1d) and tectonic lenses and larger bodies of anorthosite. The largest is the Whitestone anorthosite (ca. 1350+50 Ma.), which becomes attenuated and fragmented at its southern end, leaving boudins of less deformed material in a mylonitic anorthositic matrix. These isolated blocks, ranging in size from centimetres to metres, are confined to structural horizons that can be traced for several kilometres in the boundary shear zone. At the southwest end of the PSSZ, the assemblage kyanite-muscovite is present and implies retrograde metamorphic reworking at lower temperatures within the shear zone.

The southern edge of Parry Sound is inward dipping and lies on the basement of Rosseau subdomain. Both Rosseau and Parry Sound are overlain by the synformal migmatitic gneissic lobes of Moon River and Seguin subdomains (Fig. 2.2). Furthermore, a gravity survey across Parry Sound domain by Lindia et al. (1983) suggested that the relatively dense Parry Sound rocks have a thickness of only 4-13 km and lie on a less dense basement. This is consistent with the interpretation of Parry Sound as an early nappe structure that was metamorphosed at granulite facies depths and thrust onto the gneissic basement (Fig. 2.3). Samples have been collected from Parry Sound and the PSSZ for comparative geothermobarometry with samples collected from the map areas discussed in Chapter 3; results are presented in Chapter 5.

#### 2.2.3 MUSKOKA DOMAIN

This includes subdomains which form both the basement (deck 1 on Fig. 2.4) and the overlying migmatitic lobes (deck 3) to the Parry Sound structure (deck 2). The general characteristics of each are discussed below.

#### Go Home Subdomain (deck 1)

This contains amphibolite and relict granulite facies assemblages (Fig. 2.4) in heterogeneous gneisses that include recognisable metasediments and metaplutonic rocks. The rather irregular structures in Go Home are reworked and transposed into parallelism with the boundary shear zone that separates it from Moon River subdomain. An area in the southwest of Go Home is discussed further in Chapter 3, section 3.2.

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#### Moon River Subdomain (deck 3)

The boundary shear zone with Go Home subdomain contains numerous lenses and fragments of anorthositic gneiss that can be traced for tens of kilometres along sructural strike. The subdomain itself is a synformal lobe trending NW-SE, composed of migmatitic gneiss.

#### Rosseau Subdomain (deck 1)

It contains amphibolite and relict granulite facies assemblages. The core area in the northwest is a broad antiformal structure (Fig. 2.2). To the south an internal tectonite zone composed of highly strained gneiss is folded and truncated by and hence predates the boundary shear zone with Moon River. It is lined by slivers of anorthositic gneiss and mafic lenses. The latter includes a garnet, clinopyroxene-rich "pseudoeclogitic" rock (sample No. 85DMSR-15), and a sapphirine-bearing mafic pod (85DMSR-3, discussed in Chapter 8). The distribution of gabbroic boudins along the southwest margin of Rosseau is discussed further in Chapter 3.

#### Seguin Subdomain (deck 3)

This is another amphibolite facies, synformal migmatitic gneiss lobe. However it contains relict hypersthene-bearing charnockitic gneiss in the neck of the structure (Nadeau, 1985). In both Seguin and Moon River there is no evidence of a sedimentary protolith to the gneisses. As a result they are interpreted as forming by the remobilisation of a dominantly meta-plutonic complex which was subsequently emplaced as thrust nappes, onto the underlying gneissic basement.

In the rest of Muskoka, southeast of the foregoing subdomains, the structures are rather variable but generally northerly. Amphibolite and relict granulite facies assemblages are preserved (Fig. 2.4) in gneisses of both sedimentary and plutonic origin. The structures in Muskoka are typically truncated or transposed along the CMBBZ by the emplacement of the Central Metasedimentary Belt at around 1070-1030 Ma. (Table 2.1).

#### 2.2.4 KIOSK DOMAIN (deck 1)

Kiosk domain lies north of Algonquin and east of Britt and Parry Sound domains (Fig. 2.2). The southern part of Kiosk is characterised by an ENE-trending belt of amphibolite facies "straight" gneisses with a strong ESE-plunging lineation. The gneisses vary from mafic to quartzo-

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feldspathic or pelitic in composition. In the west this belt swings southwestward around the southern margin of a large plutonic complex, of dioritic to monzonitic composition, known as the Powassan batholith (Fig. 2.2; Davidon et al., 1986). In the southwest, near the Parry Sound and Novar structures, there is a small cluster of coronite metagabbros (Chapter 3, section 3.6) while in the northeast, there is a another relatively extensive tract of metagabbroic boudins (Fig. 1.1). The north of Kiosk domain is dominated by plutonic rocks of tonalitic to granodioritic composition which are separated from southern Kiosk by an internal high strain zone lined by mylonitic tectonites.

#### 2.2.5 ALGONQUIN DOMAIN (deck 1)

Algonquin domain is dominated by granulite facies assemblages and the SE-dipping boundary with Kiosk domain apparently marks the northern extent of granulite facies metamorphism. Thus the granulites lie structurally above the amphibolite facies gneisses in Kiosk domain. The granulites are typically strongly deformed and contain attenuated quartz rods. Algonquin domain has so far been subdivided into the following five subdomains:

#### Huntsville Subdomain

This is characterised by predominantly granulite facies, flaggy gneisses which include marble, graphite- and/or sillimanite-bearing metasediments in addition to numerous metaplutonic rocks. The subdomain is interpreted as a broad shear zone comprising several allochthonous slices of lower crustal material that was thrust onto Novar subdomain and overlain by the later emplacement of Seguin (Nadeau, 1985). Near the boundary zone with Novar, there is an elongate cluster of metagabbros which are described further in Chapter 3, section 3.7.

#### Novar Subdomain

It is composed of granulite and amphibolite facies metaplutonic and supracrustal successions. The structural trends are broadly northerly and are truncated or transposed at the margin with Huntsville. The boundary zone includes fragments of anorthositic gneiss which can be traced discontinuously into Novar where anorthositic material occurs as lenses within foliated metagabbroic rock, the latter locally becoming more mafic and approaching garnet clinopyroxenite (Nadeau, 1985). This gabbroic association is apparently unrelated to the coronite bodies. Nadeau (1985)

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interprets Novar as another allochthonous slice with an internal metamorphic and structural signature inherited from an earlier, possiblly pre-Grenvillian deformation where reworking, by the later emplacement of Huntsville, was confined to the margins.

#### McCraney Subdomain

This is dominated by amphibolite and granulite facies quartzofeldspathic gneisses with subordinate mafic material. The internal structure is broadly northerly and is folded by large scale open folds, coaxial with the east-southeast plunging stretching lineation (Culshaw et al., 1983).

#### McLintock Subdomain

The structural trends are northerly to northeasterly with major recumbent folds while lineations plunge easterly, or southeasterly in the southern part of the subdomain (Davidson et al., 1986). The structures are transposed by the Kawagama tectonite zone which seperates McLintock from Muskoka domain (Chapter 3, section 3.8). McLintock is bounded at its eastern margin by a staight belt of northwest-trending migmatites and orthogneisses, the latter truncating major fold structures in McLintock and representing the boundary with Opeongo subdomain.

#### Opeongo Subdomain

The western side is characterised by NNW-trending gneisses with a shallow southeast-plunging stretching lineation. Further east major folds, with northwest-trending axes, define domal antiforms overturned to the northwest and inclined either to the NE or SW (Davidson et al., 1986). The gneisses and granulites have both plutonic and sedimentary protoliths, the latter including calc-silicates, marble and graphite-bearing gneisses. In the east Opeongo contains a large cluster of metagabbroic rocks which are described in Chapter 3, section 3.3 (Fig. 3.4). These continue southeast of the latter map area, on the limbs of a domal structure, west and northwest of the town of Whitney.

## 2.3 DISCUSSION

The Grenville Front is a zone of high-angle reverse displacement that thrust Grenvillian rocks against an older foreland. The crustal dislocation in the form of ductile shear zones, may extend down to the Moho, but does not represent a crustal suture because Archaean, Huronian and Killarnean rocks are reworked in the Grenville Front Tectonic Zone to the south. Further south, mid- to lower-crustal displacements are reflected in amphibolite and granulite facies marginal shear zones that separate discrete crustal blocks within the Central Gneiss Belt. The structural evidence suggests Parry Sound domain is wholly allochthonous and was emplaced onto the gneissic basement at an early stage (ca. 1.18 Ga.) from lower crust undergoing granulite facies metamorphism. This occurred a during crustal thickening which eventually reached granulite grade in the Algonquin basement, some 100 Ma. later than in Parry Sound domain. The CGB is truncated at its southern end by the thrust emplacement of the dominantly supracrustal succession of the Central Metasedimentary Belt. Again this occurred approximately 100 Ma. later than the introduction of syntectonic pegmatites into the Parry Sound shear zone and implies an extended period of deformation.

consistent throughout the southwest Kinematic indicators are Grenville Province and imply northwest-directed transport of the various crustal blocks. The extreme fabric attenuation of marginal tectonites by a combination of pure and simple shear, coupled with the emplacement of granulites over amphibolite facies gneisses, suggest large relative displacements. Similar interpretations have been made in Labrador where granulite facies rocks have also been thrust onto amphibolite facies gneisses (Wardle et al., 1986). Thus the Grenville province appears to ancient thrust belt that probably resulted from continental represent an collision at around 1.1 Ga (Windley, 1986). However there is no unequivocal evidence of any suture; Windley (1986) suggests it may be represented by the Carthage-Colton mylonite zone, juxtaposing the island arc of the CMB against the CGT continent. This was followed by continued convergence and collision of the CGB against both the CGT and its accreted arc terrane (Fig. 2.1). In this model the northwest-directed thrusting and boundary shear zones in the CGB are correlated with further postcollisional convergence and indentation of the CGB continent against the rigid CGT plate. However the suture could also lie further to the southeast and be reworked in the Appalachian orogeny.

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In a plate tectonic framework the supracrustals within the Central Metasedimentary belt may have been deposited in an inter-arc basin which closed during the accretion of the CMB island arc. Crustal thickening then occurred by obduction of the whole belt from the southeast, the nappes possibly being derived from southeast of the Central Granulite Terrane (CGT). The basement to the dominantly supracrustal rocks of the Central Metasedimentary Belt is not known. In the Central Gneiss belt and the GFTZ there is no known granitic or cal-alkaline plutonism associated with the Grenvillian orogenic cycle (ca 1.3 to 1.0 Ga.). The granitoid metaplutonic rocks are all older (1.5 to 1.34 Ga) and may represent the deformed equivalents of the mid-Proterozoic magmatism in the Killarney area and more widely, in mid-continent North America, ca. 1.48 to 1.35 Ga. (Van Schmus & Bickford, 1981; Bickford et al., 1986). The metagabbros were (Chapter 6, section 6.1) but these are intruded at around 1200 Ma. relatively minor additions to the crust. As a result the metamorphism does not record additional heat from any known syntectonic plutonism and may reflect the thermal response of the crust to crustal thickening.

The tectonic lenses of anorthositic gneiss along tectonite zones may represent slices of plagioclase differentiates from large, layered complexes. In such an intrusion(s), the boundaries between relatively competent plagioclase-rich layers and more ductile, mafic material may have acted as planes of weakness along which the thrusts propagated. In contrast, the ubiquitous marbles in the Central Metasedimentary Belt may have acted as decollement surfaces (Hamner & Ciesielski, 1984), resulting in marble tectonites or tectonic breccias along the dislocation zones.

This Chapter presented a summary of recent work in southwest Grenville Province and acts as a framework for the correlation and interpretation of the complicated reaction history recorded in the metagabbroic rocks (Chapters 6 and 7). The following chapter outlines the field relations of gabbroic rocks and discusses, in more detail, the geology of the enveloping gneisses.

### CHAPTER III

## THE GEOLOGICAL SETTING OF METAGABBROIC ROCK

#### 3.1 INTRODUCTION

Coronitic olivine metagabbro bodies are common throughout the Central Gneiss Belt in Ontario. Several relatively detailed studies of the distribution of these rocks were undertaken during two field seasons with the Geological Survey of Canada. They have been found in all lithotectonic domains except Parry Sound domain, and range in size from a few metres to rarely one kilometre in longest dimension. The gabbro bodies occur singly and in concentrated or dispersed clusters of variable size, either within lithotectonic domains or as elongate clusters along marginal shear zones. This Chapter describes the general geology in several of these areas, concentrating on the dominant structures and lithologies in the metagabbros and their host gneisses. The areas are outlined in Figure 3.1 and on the large map (Fig. 1.1), which includes sample localities, in the pocket at the back of this thesis.

Five of the study areas are within lithotectonic domains: near Port Severn in Go Home subdomain; southeast Algonquin Park in Opeongo subdomain; outcrops around Lake Rosseau and Lake Joseph in Rosseau subdomain; a small cluster in Kiosk subdomain and several small, scattered clusters in Seguin subdomain. The remaining concentrations are found along boundary shear zones between structural units and two major clusters have been studied; one in the Kawagama tectonic zone near the village of Dorset, at the southern edge of McLintock subdomain; and secondly, between Huntsville and Novar subdomains. Minor disaggregated gabbroic boudins also crop out along the margins of the Moon River structure.

The gently rolling terrain is forested and gabbroic bodies normally cap rounded hills, separated by intervening lakes or swampy ground. The rocks are generally well-exposed along lake shores, but crop out poorly inland where sampling, except at blasted road-cuts, is difficult. Details of the field relations are also presented in Davidson et. al. (1985), and





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#### 3.2 GO HOME SUBDOMAIN: PORT SEVERN AREA

This area is on the coastline of southeastern Georgian Bay, between Port Severn (79°18'W and 44°12'N) and Honey Harbour (Fig. 3.2). The rocks comprise predominantly migmatitic gneiss of unknown affinity, but include marble, rare sillimanite-bearing paragneiss, recognisable granitoid orthogneiss, gabbroic and anorthositic gneiss. Some of these units provide useful markers for outlining the regional fold pattern. The Precambrian rocks are overlain unconformably by Ordovician limestone in the form of small outliers and, at the southern end of the mapped area, as the beginning of the extensive Phanerozoic cover that extends over most of North America to the south (Fig. 2.1).

Go Home subdomain is dominated by amphibolite facies assemblages. although in several places north of the mapped area, orthopyroxene-garnet granulites are preserved (sample 85DMS-2, Chapter 5). The migmatitic grey and compositionally heterogeneous with varying gneisses are quantities of quartz, feldspar, biotite and hornblende. They are cut by abundant, pink quartzo-feldspathic leucosomes that are often folded (Plate 3.1a) while pre- and syntectonic pegmatites are commonly boudinaged (Plate 3.1d). In the south of the map area there is a unit of relatively homogeneous pink, garnet-bearing orthogneiss that has a strong linear fabric defined by stretched K-feldspar megacrysts or polycrystalline aggregates (Plate 3.1b). The contact with migmatitic gneiss is exposed on the north shore of Green Island and is isoclinally folded. Similar garnetiferous orthogneiss crops out along HWY 69, north of Barron's Lake.

The gneissic trends are dominantly NW-SE and the foliation dips moderately to the south. Lineations generally plunge shallowly to the southeast, but become reoriented by shallow folds with NE-SW axial traces in the lower coastal section of the map area (inset Fig. 3.2). The area forms part of the southern limb of a large fold structure, the Baxter synform of Schwerdtner & Mawer (1982) which is inclined to the southwest and closes in the northern part of the map (Fig. 3.2). The axis runs NW-SE, approximately parallel to the dominant gneissic layering, and

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KEY Metagabbro Anorthosite Orthogneiss Pelitic Gneiss Hora Marble Palaeozoic Gneissic trend Foliation (<65\*dip) Foliation (>65 · dip) -Vertical Lineation Fold axis Boundary Shear zone Synformal axis Antiformal Gabbroic Pods UM pods Anorthositic pods Moore Pt. 0 Brousseau Port is Severn 0 GEORGIAN BAY GOHOME LINEATIONS N 20 Gr 1km ò

FIGURE 3.2: Geological map of the Port Severn area in Go Home subdomain.

### PLATE 3.1

- A: Folded amphibolite layer in migmatitic gneiss from Go Home subdomain.
- B: Granitoid orthogneiss with strong L-fabric defind by stretched feldsapr augen; part of Green Island orthogneiss unit.
- C: Highly strained and well banded blastomylonite from an internal tectonite zone at the northern margin of the westernmost metagabbro on Moore Point in Go Home subdomain.
- D: Boudinaged pegmatite in flattened migmatitic gneiss from the northern shore of Green Island in Go Home subdomain.



sub-parallel to the lineation. There is a pronounced structural change in the channel north of Green Island: the orthogneiss on the island has a regular ESE-WNW strike and moderate dip to the south, whereas gneisses on small islands and on the mainland to the north have a disrupted appearance and contain tectonic slivers of other rock types in a highly folded, migmatitic matrix. The penetrative foliation and strong stretching fabric in the orthogneiss may represent a different deformation episode, juxtaposed against the highly folded gneisses to the north along an internal high strain zone. Alternatively the granitoid may have been emplaced prior to 1.3 Ga. (by analogy with the age of other plutonic precursors. Chapter 2) into a folded, probably pre-Grenvillian gneissic basement. The strong linear fabric has been gently warped and transposed to ESE or WNW-plunging, sub-parallel to the foliation. A schematic cross-section from 'A' near Honey Harbour southeast to 'B' at Green Island is given in Figure 3.3a.

Marble is exposed in the northwest of the map area, around Honey Harbour. It has a granular texture comprising 1-2mm grains of calcite, dispersed feldspar, diopside, scapolite and some wollastonite. Grossular garnet is locally associated with diopside in calc-silicate pods within the marble. In outcrops along the road to Honey Harbour the marble is associated with a syenitic rock and pegmatite, containing amphibole and some pyroxene. This association is thin (10-20 m) but can be traced for several kilometres. A thicker marble unit (several tens of metres) to the southwest is characterised by many lensoid inclusions of folded mafic rock and porphyroclasts of feldspar and diopside-rich pods. It has the appearance of a tectonic breccia with fragments of mafic and pegmatitic material and is in direct contact with the regional migmatitic gneiss. It thins abruptly to the southeast where it appears to pinch out, possibly by thinning near the hinge of a fold.

#### 3.2.1 METAGABBROS

Olivine-bearing metagabbro forms two or possibly three bodies of medium to coarse grain size at Moore Point (Fig. 3.2). Internally the bodies show a relict ophitic texture and a primary plagioclase lamination but at the margins, against enclosing migmatitic gneisses, the gabbro is generally highly strained and converted to amphibolite. The contacts are mainly tectonic and the gabbros represent large boudins enveloped by

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FIGURE 3.3a: Schematic x-section through the western part of Figure 3.2.

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migmatitic gneiss. However, at the southern edge of the central gabbro body (Fig. 3.2) a primary contact is preserved. Here gabbro, retrogressed to amphibolite, cuts across the gneissic layering and indicates the presence of an earlier, probably pre-Grenvillian fabric in the gneissic country rock. At the northern contact of the largest body in Kamenni Bay the gabbro is juxtaposed against a vertical high strain zone in which gneisses show marked grain size reduction, contain thinned and fragmented pegmatite, and possibly exhibit sheath folds (Plate 3.1c). The adjacent gneisses commonly contain smaller lenses of amphibolite up to five metres in size, probably derived from the larger bodies by shearing.

### 3.2.2 ANORTHOSITIC GNEISS

The anorthositic gneiss crops out in long, continuous linear ridges commonly associated with a more mafic gneiss, and varies in compositon from true anorthosite to leucogabbro. It is medium to fine grained, recrystallised and strongly deformed. The deformation is reflected by thin elongate aggregates of mafic minerals defining a foliation which was subsequently folded and subjected to internal boudinage and rotation of individual anorthosite 'blocks' (Plate 3.2a). The longest ridge extends from Georgian Bay southeastward, passing north of Port Severn and extending an unknown distance farther to the southeast. This represents a minimum distance of 8-9 km, but nowhere is it greater than 8 m thick. In several places two anorthositic layers are separated by highly strained. mafic material; together this possibly reflects the original igneous stratigraphy which is now extremely attenuated. On the coast SE of Honey Harbour, the anorthosite becomes folded and coronitic leuco-gabbroic gneiss (sample 84DMS-134C) is preserved in the relatively low strain hinge-zone of a fold. The coronas consist of amphibole-garnet layers around orthopyroxene within a pod which is 2-3 m in size. There is a rapid strain gradient into foliated leucogabbroic gneiss on the limbs of the fold. To the west the anorthosite becomes discontinuous and occurs as isolated pods within migmatitic gneiss. These relations are probably the result of extensive thinning and large-scale boudinage.

A similar mechanism may explain the isolated occurrences of anorthositic gneiss in the south, north of Green Island (Fig. 3.2) where anorthosite on the south side of Brousseau Island is associated with paragneiss, the latter including a calc-silicate and sillimanite-bearing

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# PLATE 3.2

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- A: Internal break-up of anorthositic gneiss in Go Home subdomain. The fabric is defined by foliated mafic wisps which have been folded and exhibit strain gradients from more to less deformed material.
  - B: Sheared calc-silicate skarn in granulite facies gneiss from Opeongo subdomain.
  - **C:** Basic granulite cut by two pyroxene-bearing neosome, Opeongo subdomain.
  - D: Foliated and attenuated granitoid orthogneiss where lenticular feldspar augen are enveloped by quartz ribbons, Kawagama zone.



pelitic layer. Outcrops are too rare for this anorthosite to make a definitive structural marker and the metasediments are not continuous. However this second anorthositic unit may extend discontinuously, parallel to the regional trends, cropping out at Potato and Green Islands and equivalent to outcrops on the mainland, south of Post Severn.

It is difficult to explain the occurrence of anorthositic rocks in these narrow yet laterally continuous bands. If they are tectonic slices originally derived from a larger mass, they have subsequently been highly flattened, folded and boudinaged. The associated mafic layers generally behaved in a more ductile fashion, allowing the more competent plagioclase-rich anorthosite to remain relatively well preserved although commonly ruptured internally (Plate 3.2a). However, in places the anorthosite has also undergone severe ductile deformation and it too has become a "straight gneiss". The coronite metagabbros have also resisted penetrative deformation and now outcrop as large boudins within host gneisses, preserving their internal fabric because strain was taken up preferentially in the enveloping gneisses.

## 3.3 OPEONGO SUBDOMAIN: SOUTHEAST ALGONQUIN PARK

This region, centred on 78°20'W and 45°35'N, has experienced granulite facies metamorphism. The map area (Fig 3.4) includes mafic and feldspathic granulites, minor occurrences of quartzofeldspathic orthogneiss, some metasedimentary granulites and abundant occurrences of coronitic, olivine-bearing metagabbro. The orthogneiss is identifiable along HWY 60, in the SE area of the map, and contains feldspar megacrysts that define a pronounced southeast-plunging lineation. Variable degrees of deformation are documented by the transformation of this orthogneiss into a well foliated grey gneiss in which the foliation is defined by narrow, pink leucosomes but which retains no megacrysts.

The granulites are poorly understood. Some contain layers and lenses of calc-silicate material, suggesting a sedimentary protolith for at least some of the rocks. In the west, just outside the map area, a calcsilicate skarn occurs as pods of garnet and clinopyroxene in a plagioclase matrix which has been incompletely replaced by scapolite (Plate 3.2b). The granulites commonly include thin, mafic lenses and

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FIGURE 3.4: The distribution of metagabbroic rocks in southeast Opeongo subdomain (key as in Fig. 3.2).

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layers, usually complexly folded or boudinaged. These may have been mafic dykes, possibly associated with the larger gabbro masses or earlier, pregabbroic intrusives. Smaller mafic clots composed of amphibole-garnetplagioclase-pyroxene may be restites from the differentiation metasomatism that resulted in the *in-situ* formation of the pyroxene-bearing neosomes (Plate 3.2c) common to most of the granulites. At one locality large garnet porphyroblasts are enveloped by recrystallised plagioclase rotation trails, suggesting pre- and syntectonic garnet growth and northwest-directed rotation.

The dominant NNE-SSW regional trends dip to the east, but swing southeasterly with a NE dip, in the southeast corner of the map. Lineations plunge consistently to the southeast at 20-30° (inset Fig. 3.4). This is sub-parallel to the axes of minor folds and the large antiformal structure in the southeast corner of the map. Several narrow, minor shear zones, generally trending northwest, occur within both metagabbros and the enclosing granulites. Curvature of the bounding foliation shows a consistent sense of tectonic transport; the northeastern side having moved down lineation to the SE, relative to the southwest side. A schematic east-west structural cross-section showing the location of minor shear zones is given in Figure 3.3b; some conjugate shears are also present. Shearing has resulted in grain size reduction and was accompanied by hydration with the formation of amphibole-biotite assemblages in both granulites and metagabbros; locally mylonites were produced.

### 3.3.1 METAGABBROS

The metagabbro bodies tend to resist erosion and as a result. larger masses typically form hills and knolls. Some thirty bodies have so far been identified. The larger ones have both tectonic and rare intrusive contacts, the latter characterised by finer grained margins preserved texturally despite static metamorphism and recrystallisation. However because both types of contact are preserved within the same body, it is likely that primary contacts are preserved fortuitously within larger tectonic blocks comprising gabbro and granulite. A tectonic emplacement explains the foliated and sheared margins of most bodies where porphyroclasts of primary clinopyroxene and amphibole, up to 3cm in diameter, commonly show evidence of rotation (Plate 3.3a) and imply northwest-

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## PLATE 3.3

- A: Rotated primary clinopyroxene porphyroclast from the margin of a metagabbroic boudin in Opeongo subdomain; kinematic sense is indicated and implies NW-directed transport.
- B: Well preserved sub-ophitic fabric and primary igneous layering in a metagabbroic boudin from Opeongo subdomain.
- C: Very coarse grained pegmatitic segragation in metagabbro from Opeongo subdomain. Some of these "sweats" contain small amounts of interstitial quartz.
- D: Highly sheared metagabbroic boudin from the boundary shear zone between Moon River and Rosseau subdomains.



directed transport (Fig. 3.3b). Some of the smaller metagabbro bodies appear to be the eroded remnants of larger boudins. Others represent stacked wedges from tectonic slicing of larger bodies.

Internally the gabbros commonly retain a coarse, sub-ophitic texture (Plate 3.3b,c). The plagioclase laths show twinning and olivine is locally preserved. However, narrow garnet rims are always present as part of the reaction coronas around opaque oxide grains and olivine, and within cores of partly recrystallised plagioclase laths. When olivine has reacted-out, the coronas are cored by aggregates of orthopyroxene. In the least altered samples still retaining olivine, large primary clinopyroxene grains are not rimmed by garnet, although they sometimes show evidence of retrogression in the form of amphibole rims. Metre-scale primary igneous layering is exhibited by several bodies (Plate 3.3b); the layering strikes approximately east-west and dips steeply south. The igneous stratigraphy is represented by a mafic basal layer, followed upward by more plagioclase-rich material. The plagioclase differentiates at the top of each layer show a preferred magmatic orientation, parallel to the banding. This plagioclase lamination is probably the result of plagioclase in a relatively dense, iron-rich magma (Chapter 4) buoyant and it represents a crystal accumulation process. These layers show varying degress of recrystallisation and localised development of a mortar texture, which is obvious even in hand specimen. Late pegmatitic segregations containing coarse plagioclase and clinopyroxene are also present (Plate 3.3c) and suggest the residual magmatic liquids were rich in volatiles. Rarely interstitial quartz is present in the cores of these indicates that the liquids became quartz-saturated. "sweats" and Cataclasis and hydration took place within localised shear zones that cross-cut the gabbro bodies and resulted in the formation of garnet-poor garnet-free amphibolites, especially if associated with and even pegmatite; presumably the alkali-rich fluids promoted garnet loss and biotite growth. Relatively static metamorphism in some bodies, without significant deformation and hydration, resulted in the textural evolution into mafic, two-pyroxene granulites.

# 3.4 WESTERN ROSSEAU SUBDOMAIN AND THE BOUNDARY ZONE WITH MOON RIVER

Near the southwest shores of Lake Rosseau and Lake Joseph  $(79^{\circ}40^{\circ}W)$ and  $45^{\circ}15^{\circ}N$ , the rather variable structure of Rosseau subdomain is either truncated or transposed at the margin of Moon River subdomain. Gabbroic rocks occur along the boundary zone and within Rosseau subdomain (Fig. 3.5). The boundary zone is characterised by highly deformed and flattened migmatitic gneisses, commonly with a shredded appearance and dipping gently to the SW. They contain tectonic inclusions of meta-anorthosite (Plate 2.1c), documented by Davidson et al. (1982).

### 3.4.1 ROSSEAU SUBDOMAIN

In Rosseau subdomain an internal high strain zone, lined by a semicontinuous strip of anorthositic gneiss, separates a terrane of metasedimentary and metaplutonic gneisses, locally with granulite facies assemblages, to the southeast from a predominantly amphibolite facies, migmatitic gneiss terrane to the northwest. The band of anorthositic gneiss is typically well-foliated although at one locality, a relatively unstrained large block of leuco-gabbroic gneiss exhibits a relict fabric which becomes rapidly reduced (within a few metres) to a mylonite in the adjacent dislocation zone. The anorthosite contains a few mafic lenses; in the southwest one of these (sample 85DMSR-3) contains sapphirine (S in Fig. 3.5) and is discussed further in Chapter 8. So far it is the only sapphirine occurrence noted within the anorthositic gneiss, although a mafic lens on the east side of lake rosseau contains mica-corundum knots (sample 85DMSR-13A) and originally it too may have contained sapphirine. Southwest of the sapphirine locality the anorthosite can be followed for several hundred metres before being truncated by a N-S trending shear zone. This zone defined by highly flattened, strongly lineated and fine grained orthogneiss, continues south towards the margin of Moon River subdomain. The orthogneiss may represent the northern extent of the Brandy Lake complex which outcrops around the town of Port Carling to the southeast.

Structural trends are variable and generally northeasterly within the map area. Lineations are heterogeneous but generally plunge to the south (inset Fig. 3.5) and are folded along with the gneissic layering and the internal tectonite zone. The gneisses contain predominantly

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FIGURE 3.5: Distribution of metagabbroic boudins within western Rosseau subdomain (key as in Fig. 3.2).



amphibolite facies assemblages although there are some relict, hypersthene-bearing granulites. One example of the latter (sample 85DMS<u>R</u>-27), forms a ridge approximately 1 km long at the SW edge of Rosseau and is surrounded by migmatitic gneisses. The metagabbro bodies together with several, small ultramafic pods occur on either side of the internal high strain zone. In the north and west they are enveloped by migmatitic gneisses with thin amphibolite layers and lenses. The gabbroic boudins are all relatively small and recrystallised with the exception of two larger bodies which have retained a well preserved, coronitic fabric (85DMSR-28 & 82, Fig. 1.1). They both lie within the same broad structural horizon, from Lake Rosseau to Little Lake Joseph. It is likely that the remaining metagabbros were derived from boudinage of similar, larger intrusions that became variably recrystallised during the process, retaining at best a relict fabric, or becoming totally reconstituted into garnet amphibolites.

In the south and east, the gneisses only contain small boudins of material. The gabbros are typically metagabbro and ultramafic amphibolites although some retain a poor, relict fabric; at one locality a foliated vein-networks is present and consists of a network of pyroxene-plagioclase veins around darker, amphibole-rich cores. The surrounding gneisses contain units of recognisable sedimentary and plutonic origin. The dominant plutonic rock is the Brandy Lake Complex which consists of a leucocratic orthogneiss, varying from dioritic to tonalite-monzonite in composition. It has large K-feldspar megacrysts that often define a strong lineation. The colour of the unit varies from a pale olive green granulite with orthopyroxene, to a grey and pink amphibolite facies gneiss. It has a zircon age of 1450 Ma (Krogh et al., 1967), but apparently does not contain boudins of coronitic affinity although amphibolites occur near its margin.

# 3.4.2 MOON RIVER SUBDOMAIN

Migmatitic gneisses in the adjacent Moon River subdomain are of two broad types: quartzo-feldspathic gneiss and a compositionally more variable and mafic garnet-bearing, pale to dark grey migmatite. Both act as the host rocks for recrystallised gabbroic boudins along the boundary zone. The gneissic trends are consistently NW-SE and lineations plunge westerly and southwesterly towards the axis of the synform (+, inset Fig.

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3.5). The metagabbros are typically recrystallised into garnet-spotted amphibolites and commonly associated with syntectonic pegmatites. The deformation is more intense than in Rosseau subdomain, and the boudins are often highly sheared and foliated into a porphyroclastic rock (Plate 3.3d). However in one body on the highway 2 km southwest of Port Carling, the igneous texture is partly preserved by strings of garnet pseudomorphing plagioclase laths in a clinopyroxene-rich matrix (85DMSR-38).

## 3.5 SOUTHWESTERN KIOSK DOMAIN: RAINY LAKE

In the shear belt east of Parry Sound domain, in the southwest corner of Kiosk domain (Figs. 1.1 and 2.2), well-preserved, coronitic olivine metagabbros occur singly and in small clusters (Fig. 3.1). A group near Rainy Lake (79°30'W and 45°15'N) has been mapped and sampled extensively (Fig. 3.6). The surrounding amphibolite grade gneisses vary from streaky, relatively mesocratic mafic migmatites to leucocratic migmatites containing rare, relict K-feldspar megacrysts in the mesosome, suggesting derivation from a granitoid plutonic protolith. The southern margin of the gabbro body immediately northeast of Rainy Lake is probably a chilled margin; gabbro at the contact is fine grained, and coarsens towards the interior of the body. The large body southeast of Rainy Lake is locally very coarse grained with primary feldspar laths in excess of 2 cm. In the latter examples the coronas around olivine and oxides have very narrow garnet rims, implying very little reaction. These two boudins are enveloped by the gneissic trends and are separated by a zone of highly strained and steeply dipping gneisses (Fig. 3.6).

In the smaller boudins and in the cluster northwest of Rainy Lake (Fig. 3.6) the gabbroic bodies exhibit greater recrystallisation, locally developing garnet-spotted textures, although some parts do retain a relict igneous fabric. The largest gabbro mass forms a hill where the contact with underlying megacrystic orthogneiss is exposed on the northfacing slope and is a zone approximately 1 m wide of sheared and cataclastic gneiss and gabbro, cut by syntectonic pegmatites.

Further northwest near the village of Magnetawan, a small coronitic metagabbro body, approximately 50 m in diameter, contains well preserved, fine grained metagabbro with minimal garnet development. This grades

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FIGURE 3.6: Coronite metagabbros in southwest Kiosk domain.



FIGURE 3.7: Boudins of metagabbro in the southern part of Seguin subdomain.



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rapidly into a garnet-spotted, clinopyroxene-rich recrystallised rock. At the margins it is strongly retrogressed into an amphibolite and has been fragmented into small pods, ranging in size from a few centimetres to metres, in a matrix of sheared pegmatitic gneiss.

## 3.6 SEGUIN SUBDOMAIN: SOUTH AND WEST OF HUNTSVILLE

The Seguin structure contains amphibolite facies migmatites, although a hypersthene-bearing charnockitic orthogneiss crops out in the neck of the synformal, migmatitic gneiss lobe (Nadeau, 1985). Metagabbroic rocks occur adjacent to Huntsville subdomain and are of several types. West and northwest of Lake Vernon a few relatively large bodies, reaching 1km in longest dimension, crop out in migmatitic gneiss and are well preserved internally with olivine coronas (samples 85DMSH-4A to F and 85DMSH-101A to D). The margins of these and several smaller bodies are typically recrystallised and retrogressed into garnet amphibolites, although some small boudins do retain a relict but recrystallised fabric (Plate 3.4a).

South of Huntsville and west of Mary Lake (79°18'W and 45°12'N), where the Seguin structure merges with the rest of Muskoka domain, even the larger gabbroic bodies in a cluster within migmatitic gneiss are recrystallised (Fig. 3.7). In places relatively static metamorphism has resulted in garnet pseudomorphs of plagioclase laths in a matrix of relict primary clinopyroxene and plagioclase (Plate 3.4b). However the textures are extremely heterogeneous and this fabric is immediately adjacent to a foliated vein-network structure (Plate 3.4c). Here the vein material consists of the anhydrous assemblage plagioclase-hypersthemeaugite. and surrounds dark cores containing plagioclase-biotiteamphibole-garnet. The smaller metagabbro bodies nearby (Fig. 3.7) are garnet amphibolites which have been foliated and interleaved tectonically with the surrounding migmatites. The gabbroic foliation is typically truncated at the contacts by steep gneissic trends which are also sites of pegmatite injection. In general the gneisses strike NW-SE with variable dips to the northeast and southwest, but steepen at the contacts with metagabbros where the foliation envelops the mafic lenses. Lineation plunge consistently to the southeast (Fig. 3.7). Small (less than metre-size), boudin-like amphibolite layers in the surrounding migmatitic

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## PLATE 3.4

- A: Recrytallised metagabbro from Seguin subdomain which still retains a relict sub-ophitic fabric defined by stellate granular plagioclase as pseudomorphs of primary laths.
  - B: Evolved metagabbro (85DMSS-18) retaining a relict fabric because relatively static metamorphism has resulted in almost complete garnet pseudomorphs of plagioclase laths; Seguin subdomain.
- C: Foliated and folded vein-network metagabbro (85DMSS-1C) from the sample in Plate 3.4B. The lighter vein material comprises opx-cpx-plag+gt and surrounds darker cores of amph-plag-gt+pyx.

D: Internal shear zone in metagabbroic boudin from the Kawagama zone.



gneiss may represent the extreme products of this tectonic break-up of former large gabbroic masses. If so, a gabbroic parentage may also apply to many of the amphibolite pods common to gneisses in many parts of the Central Gneiss Belt.

## 3.7 NOVAR-HUNTSVILLE BOUNDARY ZONE: NORTH OF LAKE VERNON

This boundary zone lies north and northwest of the town of Huntsville (79°15'W and 45°20'N). It is characterised by flaggy, well banded L-S tectonites which locally include fragments of ultramafic and anorthositic gneiss as well as an elongate cluster of metagabbros (Fig. 3.8). The rather variable NNW strike in Novar subdomain is either truncated or transposed into parallelism with the trend of the boundary zone. Nadeau (1985) proposed that the boundary zone represented the site of northward-directed thrusting of rocks in Huntsville subdomain over those of Novar, before the emplacement of Seguin subdomain which lies to the south. The lineations in the boudary zone plunge to the southeast and west, bending around gabbroic boudins (inset Fig. 3.8). This suggests continued extension and boudinage during and after the emplacement of the Huntsville structure. Lineations south of the boundary zone plunge consistently to the south, and turn southeasterly towards the contact with Muskoka domain (Nadeau, 1985). Both Huntsville and Novar subdomains contain amphibolite and granulite facies assemblages derived from both plutonic and sedimentary protoliths, the latter represented by graphite and sillimanite-bearing gneisses and rare marble in the Huntsville area. Further details of the major lithologies are in Nadeau (1985), only the distribution of gabbroic rocks will be discussed in detail here.

In general the enveloping gneisses are highly strained, fine grained and commonly show isoclinally folded layering adjacent to the gabbroic masses. Local mobilisation at the contacts between gneiss and metagabbro has produced chaotic interleaving of migmatitic gneiss, pegmatite and recrystallised gabbro. The gneissic protolith is identifiable in the northwest part of Lake Vernon as a tonalitic metaplutonic rock (the Lake Vernon suite of Nadeau, 1985). To the east the metagabbroic rocks are surrounded by highly strained, well banded gneiss of uncertain affinity which constitutes most of the subdomain boundary zone. However rare, relict K-feldspar megacrysts in relatively less-strained gneiss from the

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# FIGURE 3.8: Distribution of metagabbroic boudins along the boundary zone between Novar and Huntsville subdomains.



northeast corner of the map, suggest here too the protolith may be plutonic.

### 3.7.1 METAGABBROS

The cluster of metagabbroic bodies along the boundary shear zone is shown in Figure 3.8. The bodies vary in size from small pods (about 5 m in diameter) to large masses, reaching 800 m in longest dimension. The contacts are normally tectonic, although possible examples of original fine grained intrusive margins were noted in two places, one of which is sketched in Figure 3.9A. Here it appears that two gabbroic pods were once part of a single body with a primary chilled margin. Later deformation led to fragmentation, shearing and recrystallisation of this body into two pods of garnet amphibolite, in places still retaining a relict fabric, but separated by remobilised, tightly folded and highly strained gneiss. Such small-scale tectonic reworking can also account for the overall map pattern through a combination of boudinage and tectonic slicing of a few, formerly larger gabbroic intrusions. Boudins of metagabbros are represented in Figure 3.9B; topographically they form knolls separated by valleys containing steeply dipping gneisses. Tectonic stacking is inferred northwest of Big Island and shown schematically in Figure 3.9C; the individual bodies have foliated margins truncated by steeply dipping gneiss in which rotated feldspar augen indicate a northward transport direction.

Unrecrystallised plagioclase laths are only present in the cores of larger bodies. Coronas are present but olivine has been replaced almost everywhere by brown aggregates of orthopyroxene. The gabbro margins are either retrogressed and reworked to fine grained garnet amphibolites, or deformed to a foliated, clot-textured rock in which primary clinopyroxene porphyroclasts are surrounded by amphibole. These "clots" have been variably flattened, rotated and enveloped by recrystallised plagioclase. Further deformation led to a crude foliation defined by attenuated mafic lenses and interlayers of fine-grained feldspathic material. FIGURE 3.9: Sketches of gabbroic field relations in the Huntsville area.







### 3.8 LAKE KAWAGAMA: EAST AND NORTHEAST OF DORSET

In the vicinity of Kawagama Lake, northeast of the village of Dorset  $(78^{\circ}55'W \text{ and } 45^{\circ}13'N)$ , McLintock subdomain belonging to Algonquin domain, is separated from the northeastern extension of Muskoka domain by a southeaterly dipping shear belt. It is approximately 4 km wide and is known as the Kawagama Zone (Culshaw et al., 1983).

McLintock subdomain contains recognisable metasedimentary and granitoid plutonic gneiss interlayered with gneiss and granulite of unknown affinity. A characteristic orthogneiss is granodioritic and contains feldspar megacrysts or flattened feldspar-aggregate augen, up to 3 cm long, and locally contains relict hyperstheme. The metasediments include pelitic and semi-pelitic units and again are hyperstheme-bearing in places. Major fold structures are present and are apparently truncated by the Kawagama shear zone.

Muskoka domain, southeast of Kawagama Lake, is composed predominantly of heterogeneous migmatitic gneisses. It does not contain rocks of unequivocal sedimentary origin. Instead highly deformed metaplutonic rocks are present, and include small patches of charnockitic rocks in an otherwise amphibolite facies terrane. Southeast of the Kawagama zone the gneissic trends swing southward and so define large-scale open folds with gently east-southeast plunging axes.

### 3.8.1 KAWAGAMA ZONE

The boundary zone at Kawagama Lake is shown in Figure 3.10 and contains both granulite and amphibolite facies assemblages. It is characterised by a concentration of metagabbroic lenses, thin and continuous layers of orthogneiss, some recognisable metasedimentary units and a few ultramafic bodies with rare garnet and spinel, all within a gneiss. One orthogneiss layer, a host of flattened migmatitic characteristic pink quartz-syenite (S in Fig. 3.10) with rare garnet, has been traced discontinuously for 12 km and is only 50-150 m thick. Two further plutonic layers lie to the northwest; the upper one can be traced discontinuously down to HWY 35, near Dorset. It has a similar composition to the orthogneiss immediately north of the Kawagama zone and may represent a tectonic sliver of this body. The central orthogneiss unit

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FIGURE 3.10: Geological map of the Kawagama zone (key as in Fig. 3.2).



has a quartz-rich granitic composition in which K-feldspar megacrysts are variably flattened, parallel to the foliation and enveloped by attenuated quartz rods and fine mafic wisps (Plate 3.2d).

The gneissic rocks strike NE-SW and dip southeasterly at 15-30°, and have a strongly developed down-dip lineation (inset Fig. 3.10). The foliation tends to steepen and wrap around the metagabbro bodies. Late, small-scale extensional shear folds occur locally near the southwest end of Kawagama Lake. The Kawagama zone contains several topographically defined lineaments sub-parallel to its length. These probably represent high strain zones along which the late differential displacement took place between Muskoka and Algonquin domains. One lineament, at River Bay on the northwest side of Kawagama Lake, is lined by mylonitic and cataclastic gneiss with a pronounced SE-plunging lineation. Pseudotachylyte veins cut the gneiss and probably represent the latest tectonic activity along this zone.

#### 3.8.2 METAGABBROS

The metagabbroic rocks show great textural variety in both their degree of recrystallisation and deformation. The largest body retains a coronitic interior with olivine and unrecrystallised plagioclase laths. In general however, the bodies have been reworked into amphibolite or vein-network metagabbro with only patches of relict but recrystallised or porphyroclastic fabrics left. All the contacts are tectonic and are usually associated with deformed, syntectonic pegmatite. Relict textures become highly flattened at the margins of the bodies and vein-networks become foliated and in some places, isoclinally folded. The vein material contains granulite facies pyroxene-plagioclase assemblages. Tectonic stacking is inferred on ridges where strongly foliated, porphyroclastic metagabbroic lenses on the lower slopes are separated from those above that characteristically cap the ridges, by highly strained gneiss. Internal shearing with a component of right-lateral shear, observed within a gabbro pod isolated by boudinage, may be a small scale example of the overall tectonic mechanism in the Kawagama zone (Plate 3.4d).

Metagabbro bodies of coronitic affinity have not been unambiguously identified to the northwest, in the immediately adjacent part of McLintock subdomain; rare amphibolite pods are present, but may be unrelated to the gabbro suites discussed here. However metagabbros are common in Muskoka domain, though more widely dispersed than in the Kawagama zone itself. Some relatively well preserved metagabbro bodies on the shores of Raven Lake are medium to coarse grained with a patchy, relict fabric of mafic coronas cored by an orthopyroxene aggregate but typically, the plagioclase laths have recrystallised and contain garnet in the centre of the granoblastic plagioclase mosaics. The majority of bodies are either garnet-spotted amphibolites or vein-networks with two-pyroxene neosomes, and some are strongly lineated. Again a foliation developed at the margins is commonly truncated at the contact with the surrounding gneiss.

## 3.9 SUMMARY

The Central Gneiss Belt in Ontario is divisible into several lithotectonic domains containing amphibolite and granulite facies assemblages. The domains, interpreted as thrust slices (Chapter 2), contain metagabbroic and anorthositic material where the original igneous fabris has been preserved in various stages of degradation. The gabbroic bodies are generally small and equant but tend to be concentrated in specific areas. either along boundary shear zones or internally within the various subdomains. The contacts with enveloping gneisses are generally tectonic and their present distribution can be accounted for by map-scale boudinage of former large gabbroic masses during ductile deformation. The gabbros acted as relatively competent bodies and deformed by failure, rather than plastic flow. As a result the interiors are typically well preserved texturally, lacking a foliation, but exhibiting reaction rims around primary olivine and opaque oxides; olivine-plagioclase being unstable at mid- to lower crustal depths but olivine surviving, separated from by coronas involving pyroxene and garnet. The field plagioclase relationships alone can shed no further light on whether corona-forming reactions occurred during subsolidus cooling from magmatic temperatures at mid-crustal depths, or because of a pressure increase during crustal thickening. Further constraints are discussed in Chapter 6.

However after corona formation the metagabbros record a complicated textural evolution involving deformation, recrystallisation and relatively static metamorphism. Deformation at the margins and

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internally, led to hydration and the formation of amphibolites and porphyroclastic fabrics, locally producing mylonites. Static metamorphism resulted in the recrystallisation of plagioclase and greater growth of garnet, sometimes completely pseudomorphing plagioclase. Complete textural equilibration resulted in the formation of mafic granulites or garnet amphibolites. Further details of the petrography and textural changes are discussed in chapter 6.

Primary igneous layering has been observed in a few metagabbros, but this is rare. The cryptic mineral and whole-rock variation within any one body is commonly as great as the variation within clusters (Chapter 4). It thus seems unlikely that their present distribution represents the break-up of large, layered mafic complexes. In addition many bodies have a relatively uniform fine to medium grain size. This, together with the rare preservation of primary chilled margins, suggests they may be derived from relatively narrow intrusions, such as dykes or sills. Further constraints on the origin of the gabbros from whole rock chemistry are discussed in Chapter 4. The cryptic mineral variation from fractionation processes is outlined in Chapter 6.

Anorthositic gneiss was emplaced as tectonic slivers and fragments within subdomains and along the boundary zones between lithotectonic domains (Chapter 2). Whole rock chemical evidence for their tectonic derivation from plagioclase-rich differentiates within larger intrusion(s) is discussed in Chapter 4. Furthermore their field relationships and chemistry suggest they are unrelated to the coronite metagabbros.

The surrounding gneisses commonly have an unknown protolith, although several units of plutonic and sedimentary origin have been recognised. However many contain assemblages suitable for P-T determination and this is discussed, along with their petrography, in Chapter 5. This, coupled with the field observations, provides a basis for discussing the physical conditions of metamorphism affecting the reaction and deformation history of the metagabbroic rocks and is considered further in Chapter 6.

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## CHAPTER IV

# WHOLE ROCK GEOCHEMISTRY OF METAGABBROS AND ANORTHOSITES

## 4.1 INTRODUCTION

This chapter discusses the major and trace element chemistry of metagabbros and anorthositic rocks. A major aim is to determine the likely tectonic setting of the gabbroic magmatism that took place at around 1200 Ma., and to establish whether the metagabbros can be derived from a common magma by fractional crystallisation of any reasonable assemblage. In addition, the analyses are compared with other areas of middle Proterozoic basaltic magmatism including the Adirondack Highlands in New York state. Nain Province, central Labrador and southern Greenland. With the exception of the Adirondack samples, these dykes are unmetamorphosed and may represent the higher level equivalents of the continental magmatism that gave rise to the dyke- or sill-like bodies in the Central Gneiss Belt (CGB).

The localities of samples are given on Figure 1.1, in the pocket at the back of this thesis, while Appendix I lists grid references and a summarised petrography for both whole rock and probe samples. Major and trace element analyses were obtained using the X-ray fluorescence spectrometer at Leicester University. A brief description of the technique is given in Appendix II which lists the XRF results and discusses the recalculation of normative compositions.

### 4.2 METAGABBROS

The field relations of the metagabbros were discussed in Chapter 3 and only features relevant to the igneous processes are mentioned here. Several samples have been altered by fluid infiltration and metamorphism and are not included in the whole rock plots presented here, but are discussed further in Chapter 6, section 6.4.5. The texturally unaltered samples range from medium-grained (3-5 mm) where plagioclase laths may

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reach 10mm in longest dimension, to coarse-grained in Fe-rich samples from Opeongo subdomain. The latter are locally very coarse and contain primary, sub-ophitic clinopyroxene up to 3-4 cm in size. They also exhibit the greatest cryptic mineral variation (Chapter 6) and well preserved primary igneous layering (Plate 3.3b), providing macroscopic evidence of crystal settling and cumulus plagioclase. In addition they show evidence of latestage fluid activity that resulted in very coarse grained clinopyroxeneplagioclase segregations containing crystals up to 10 cm in size (Plate 3.3c). These "sweats" or pegmatitic segregations rarely contain small amounts of interstitial quartz and suggest silica became saturated in the fluid-rich melt. In other gabbroic clusters the common observation of a plagioclase lamination supports some crystal-liquid separation.

The order of crystallisation was olivine-plagioclase followed by opaque oxides which preceded or overlapped the crystallisation of primary clinopyroxene. The present "metamorphic" and proposed primary modal proportions for the least-evolved and medium-grained metagabbros are presented in Chapter 6. section 6.4.3 and are summarised below in Table 4.1. The only major phase which shows a large variation in modal abundance is clinopyroxene and it is macroscopically most abundant in the Fe-rich Opeongo samples.

TABLE 4.1: A summary of estimated primary modal proportions.

OLIVINE: 17-23 % in magnesian metagabbros (Fo50-60); 10-15 % in Fe-rich metagabbros PLAGIOCLASE: 60-68 % PRIMARY CPX: 7-11 % (Mg-rich); 10-18 % (Fe-rich metagabbros) OPAQUES (Mt/Ilm): 5-10 % APATITE: approximately 0.1-1.3 %

The comparable modal proportions suggest that although some crystal accumulation has no doubt taken place, not one of the medium-grained samples represent well-developed cumulates. Extensive crystal settling may only have taken place in the Fe-rich and evolved Opeongo liquids, resulting in the cumulates and macroscopic igneous layering; their Fe-rich nature resulting in a greater density contrast between plagioclase and mafic phases. Furthermore, the recalculated primary plagioclase compositions (Chapter 6, section 6.4.3) suggest that Fe-rich samples also originally contained more sodic plagioclase (An42-48).

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Clinopyroxene occurs as an interstitial phase, or in sub-ophitic to poikilitic intergrowths with plagioclase, depending on modal proportions; larger crystals commonly enclose olivine and opaque oxides. Clinopyroxene is a late phase and can become concentrated in relatively evolved liquids. The margins of primary clinopyroxene and plagioclase commonly contain apatite inclusions. In addition zircon and baddelyite have been identitfied in interstitial and mesostasis areas between plagioclase laths. These observations are discussed and possible fractionating assemblages quantified in terms of major elements, in the following section.

Olivine composition ranges from  $Fo_{27-50}$  throughout the gabbroic suite and can vary by 10-15% Fo within individual bodies. In the following pages a specific concentration of gabbroic boudins is referred to as a 'cluster', whereas the term 'suite' encompasses all the metagabbros. The original plagioclase composition is obscured by later, subsolidus coronaforming reactions and is clouded with spinel inclusions. However, by using the integrated Al, Si content (Chapter 6) and the normative An/(An+Ab) ratio (Fig. 4.1a) it is inferred to be around  $An_{50-55}$  although, as mentioned above, it was apparently more sodic in the Fe-rich samples (Table 6.6). Subsolidus processes are also responsible for the loss of the primary opaque oxide phase. This resulted in the formation of ilmenite from magnetite because iron was lost preferentially to form biotite, amphibole and the (gt-cpx) symplectites. Some samples do retain primary titaniferous magnetite with fine grained ilmenite lamellae (Plate 6.5d), as well as discrete ilmenite grains and this probably represents the original opaque mineralogy.

Primary clinopyroxene is clouded with ilmenite inclusions which contribute up to 2 Wt.7 TiO<sub>2</sub> to microprobe analyses. This reflects an integrated primary composition that is titaniferous, but not quite a titanaugite. Presumably during slow cooling or metamorpism the titanium was exsolved as fine-grained ilmenite "dust". High primary contents of TiO<sub>2</sub> suggests that the rocks have a mildly alkaline character and this is further substantiated by the presence of small amounts of primary, interstitial biotite. Thus the residual liquids were progressively enriched in  $P_2O_5$ ,  $K_2O$  and Zr until the latter became compatible and apatite, biotite and Zr-bearing minerals precipitated. Further details of the petrography and mineral chemistry are discussed in Chapter 6 and are summarised in Appendix I.

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FIGURE 4.1a: Differentiation index (norm Qtz+Ab+Or+Lu+Ne) vs. normative An/An+Ab for metagabbros, anorthosites and leucogabbros.



FIGURE 4.1b: Normative Ne-Ol-Di-Hyp for mid-Proterozoic basaltic magmatism in the southern Canadian shield and Greenland (note symbols in LHS are inverted).



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SAMPLE	DMSK10	850MS6	85DMS8	84A118	84A11C'	MSH101D	DMSR28	DMSD68	DMSD68A
Si02	45.5	47.2	46.4	45.4	45.7	46.5	46.2	46.3	46.5
T102	2.02	1.59	1.67	3.29	3.37	2.81	2.23	2.81	2.32
A1203	17.0	18.7	18.2	16.8	16.7	18.2	18.1	18.0	17.6
Fe203	2.2	2.3	3.0	3.7	3.7	1.9	2.4	2.9	3.0
Fe0	11.3	8.4	8.5	10.8	10.9	11.0	10.1	10.2	10.2
MnO	0.18	0.14	0.15	0.19	, 0.20	0.17	0.16	0.17	0.17
MgQ	8.8	7.6	8.3	6.4	6.2	6.0	7.7	6.4	6.5
CaO	7.9	8.4	8.2	7.8/	7.9	8.7	8.3	8.4	8.3
Na20	3.2	3.1	2.9	3.9	3.2	3.5	3.0	3.7	3.6
K20	0.69	0.63	0.64	1.04	1.02	0.86	0.70	0.92	0.85
P205	0.33	0.24	0.27	,0.66	0.69	0.42	0.34	0.47	0.45
LOI	ND	ND	ND	/ ND	ND	ND	ND	ND	ND
Total	99.15	98.33	98.32	/ 99.95	99.64	100.00	99.25	100.24	99.45
Trace els	ements i	n parts :	per mill	lion					
Cr	100	85	116	27	27	30	51	29	116
v	142	112	114	224	219	199	137	181	172
Ba	272	248	/243	385	389	345	280	358	335
La	9	8	· 7	21	22	12	10	16	13
Ce	25	21 /	21	40	38	30	28	35	36
Nd	18	14 /	13	24	26	19	18	24	24
NЬ	8	7	7	12	13	10	8	11	10
Zr	104	79	83	172	176	149	107	149	140
Sr	22	,18	17	33	33	27	22	29	28
RЬ	480	537	505	520	518	589	643	593	608
Th	8	<sup>7</sup> 10	8	14	14	15	9	12	10
Ga	4	; 6	4	2	2	2	5	5	6
Zn	22 /	ʻ 22	21	24	24	22	22	25	25
Ni	117	91	97	119	121	115	110	110	110
C.I.P.W.	/ norms								
Qtz	Ĺ.								
Cor	/								
Or	4.08	3.72	3.78	6.15	6.03	5.08	4.14	5.44	5.02
Ab	/24.41	26.23	24.79	27.39	27.08	26.62	24.96	27.27	28.23
An	29.90	35.31	34.68	25.27	28.20	31.42	34.20	29.82	29.44
Lu									
Ne 🦿	1.54			3.04		1.62		2.05	1.17
Ac									
Ns '									
Di	5.80	3.86	3.55	7.46	5.32	7.43	3.77	7.07	7.14
Ca									
Wal									
Hy		6.34	6.74		5.92		5.05		
01	25.64	15.96	16.63	17.55	13.71	18.83	18.64	17.96	18.55
Mt	3.19	3.33	4.35	5.32	5.39	2.68	3.48	4.20	4.JD
Ilm	3.84	3.02	3.17	6.25	6.40	5.34	4.24	5.34	<b>~. ~ !</b>
Hm					~~				
Ru								1 00	1 04
Åp	0.76	0.56	0.63	1.53	1.60	0.97	0.79	1.03	1.04

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TABLE 4.2: XRF results for proposed parental liquids for the CGB metagabbros.

Very few unquestionable chilled margins have been identified and this restricts the choice of samples that represent true, quenched parental liquids. However the margins of some bodies are finer-grained (notably 84DMSA-11b' and c') than the interior and although the actual contacts are tectonic and commonly reworked and hydrated into amphibolites, it is inferred that samples with fine-grained, relict fabrics represent chilled marginal suites whose composition approximates the parental liquid. The analyses and norms from these samples are listed in Table 4.2 and highlighted in the variation diagrams presented in Figures 4.7 to 4.10. It is stressed that these are equivocal parental liquids, although a lot of confidence can be placed on two samples from Opeongo where the gabbroic interiors are very coarse-grained. However, as there is very little modal variation in the magnesian samples and no evidence of extensive cumulateforming processes, it is proposed that the other samples are also reasonable approximations to parental liquids whose actual composition was not greatly altered during crystallisation; the whole rock chemistry, discussed in the following sections, does not contradict this.

### 4.2.1 MAJOR ELEMENT GEOCHEMISTRY

The chemical analyses and norm calculations are given in Appendix II and presented graphically in Figures 4.1, 4.2, 4.3 & 4.4. The arrows in Figure 4.2 are vectors that represent the effect of subtracting that phase in the composition space. In terms of norms (Fig. 4.1) the rocks plot either in the Ol-Di-Hy triangle, or just within the undersaturated nepheline field. All the samples are rich in normative olivine relative to pyroxene and hence have a troctolitic character. The Harker diagrams (Fig. 4.2a-f) show the variation between and within gabbroic clusters. On the total alkalis vs. silica plot (Fig. 4.2f), the proposed CGB parental liquids plot just within the alkali basalt field implying a transitional tholeiitic to alkaline character. On an AFM diagram (Fig. 4.3) they lie towards the tholeiitic trend, i.e. some iron enrichment with increasing alkali content. TABLE 4.2: XRF results for proposed parental liquids for the CGB metagabbros.

SAMPLE	omsk10	850MS6	850MS8	84A118'	84A11C	MSH101D	omsr28	DMSD68	DMSD68A
S102	45.5	47.2	46.4	45.4	45.7	46.5	46.2	46.3	46.5
T102	2.02	1.59	1.67	3.29	3.37	2.81	2.23	2.81	2.32
A1203	17.0	18.7	18.2	16.8	16.7	18.2	18.1	18.0	17.6
Fe203	2.2	2.3	3.0	3.7	3.7	1.9	2.4	2.9	3.0
Fe0	11.3	8.4	8.5	10.8	10.9	11.0	10.1	10.2	10.2
MnO	0.18	0.14	0.15	0.19	0.20	0.17	0.16	0.17	0.17
MgO	8.8	7.6	8.3	6.4	6.2	6.0	7.7	6.4	6.5
CaO	7.9	8.4	8.2	7.8	7.9	8.7	8.3	8.4	8.3
Na20	3.2	3.1	2.9	3.9	3.2	3.5	3.0	3.7	3.6
K20	0.69	0.63	0.64	1.04	1.02	0.86	0.70	0.92	0.85
P205	0.33	0.24	0.27	0.66	0.69	0.42	0.34	0.47	0.45
LOI	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total	99.15	98.33	98.32	99.95	99,64	100.00	99.25	100.24	99.45
Trace el	ements i	n parts	per mill	lion					
Cr	100	85	116	27	27	30	51	29	116
V	142	112	114	224	219	199	137	181	172
Ba	272	248	243	385	389	345	280	358	335
La	9	8	7	21	22	12	10	16	13
C•	25	21	21	40	38	30	28	35	36
Nd	18	14	13	24	26	19	18	24	24
Nb	8	7	7	12	13	10	8	11	10
Zr	104	79	63	172	176	149	107	149	140
Y	22	18	17	33	33	27	22	29	28
Sr	480	537	505	520	518	589	643	593	608
Rb	8	10	8	14	14	15	9	12	10
Th	4	6	4	2	2	2	5	5	6
Ga	22	22	21	24	24	22	22	25	25
Zn	117	91	97	119	121	115	110	110	110
Ni	155	150	147	89	90	85	152	101	97
C.I.P.W.	norms								
Qtz		-							
Cor									
Or	4.08	3.72	3.78	6.15	6.03	5.08	4.14	5.44	5.02
Ab	24.41	26.23	24.79	27.39	27.08	26.62	24.96	21.21	28.23
An	29.90	35.31	34.68	25.27	28.20	31.42	34.20	29.82	29.44
Lu									4 47
Ne	1.54			3.04		1.62		2.05	1.11
Ác	~~								
Na								7 07	7.14
Di	5.80	3.86	3.55	7.46	5.32	(.43	3.11		
Ca.									
Wo1							5 05		
Ну		6.34	6.74		5.92	40.92	10 64	17.96	18.66
01	25.64	15.96	16.63	17.55	13.71	19.69	3 10	<b>↓</b> ,20	4.35
Mt	3.19	3.33	4.35	5.32	2.38	5.00 5.00	4.24	5.34	4.41
Ilm	3.84	3.02	3.17	6.25	6,40	3.34			
Hm									
Ru							Ŋ 79	1.09	1.04
Ap	0.76	0.56	0.63	1.53	1.60	0.3(	0.13		

FIGURE 4.2: Major element variation diagrams for metagabbros from the Central Gneiss Belt (CGB). Proposed parental liquids are marked by ( ), while vectors represent the effect of addition (+) and subtraction (-) of the indicated minerals (An52, Fo55).





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The major element variation between clusters (intra-suite) could be the result of varying degrees of fractional crystallisation from a common magma prior to intrusion; i.e. consanguineous intrusions. Subsequently, *in-situ* fractionation processes resulted in the cryptic mineral and whole rock variation within individual intrusions. There is no correlation between MgO and SiO<sub>2</sub> (Fig. 4.2d), suggesting that olivine was not a major fractionating phase. Similarly the lack of a correlation between CaO and MgO implies fractionation of clinopyroxene was not important. The positive correlation between Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> favours plagioclase fractionation as an important control on the liquid evolution. There is a negative correlation between TiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>T and SiO<sub>2</sub> (Figs. 4.2a & c) which is reflected in the greater modal proportions of opaque oxides (as cumulate phases) in the Fe-rich samples (Chapter 6, section 6.3.4).

The minor elements K, P and Ti are plotted against MgO on Figure 4.2g,h & 4.4a. As expected, the Mg-poor compositions are most fractionated and enriched in these elements, whereas they behaved incompatibly in the magnesian clusters. Of note is the change in gradient at approximately 6-7 Wt.7 MgO which may represent the point where apatite and biotite became important, minor fractionating phases.
Modelling of likely *in-situ* fractionating assemblages has been attempted using a least squares petrological mixing program for major element abundances (Bryan et. al., 1969). A summary of the results is given in Table 4.3. All possible fractionating phases were included, using analysed mineral compositions and a plagioclase composition of  $An_{52}$ . The fit of the proposed assemblage to the initial liquid is given by the sum

of squares of residuals. The best approximations to the parental liquids for each cluster (as discussed earlier) are given by chilled marginal samples from Opeongo subdomain (84DMSA11b' & c') and from samples with finer-grained relict fabrics which were collected near to the present margins of other bodies. The contact amphibolites have been avoided because deformation and infiltration by hydrous fluids undoubtedly altered chemistry, especially the alkali content. Because of uncertainties in the the choice of parental liquids the results in Table 4.3 are only intended qualitative to impression of the possible fractionating give а assemblages. However the results are consistent and suggest fractionation of 2-3 times more plagioclase (up to 50%) than olivine (up to 26%). This is compatible with the vectors on Figure 4.2b,d where the removal of plagioclase enriched the liquids in MgO and FeO and effectively swamped the influence of olivine fractionation which otherwise would have depleted the liquids in MgO, thus resulting in no correlation between MgO and SiO, (Fig. 4.2d). Clinopyroxene fractionation apparently had a negligible effect on the liquid evolution.

The major element variation between clusters has also been modelled. The proposed fractionating assemblage from the least evolved and most Mg-rich "parental" composition (85DMS-6), to each of the initial liquid compositions given in Table 4.2, is presented in Table 4.4. As before the results infer that plagioclase and lesser amounts of olivine were the dominant fractionating phases.

In summary the major element chemistry suggests the removal of plagioclase, accompanied by lesser amounts of olivine, was responsible for the liquid evolution between clusters of gabbroic rocks. This implies plagioclase was fractionating from the parental liquid either during ascent, or within some lower crustal reservoir. This depleted more evolved liquids progressively in alumina prior to intrusion and lowered the Ancontent of plagiolcase in more evolved metagabbros. During emplacement, the liquids underwent plagioclase fractionation which produced the

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TABLE 4.3: Least squares modelling of proposed fractionating assemblages within individual clusters;
+ indicates addition, - removal of a phase from a fractionating liquid.

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INITIAL LIQ	RESIDUAL LIQ	OLIVINE	CPX	PLAG	MAG-USP	APATITE	BIOTITE	ILMENITE	"FIT"
84A118 <sup>′</sup>	85A11A = 0.20	0.24	0.04	0.45	-0.07	0.01	0.05	0.06	0.35
•	84A11E <sup>°</sup> = 0.16	0.26	0.02	0.49	-0.08	0.02	0.05	0.07	0.43
•	$85 \times 163 = 0.23$	0.24	0.02	0.44	-0.07	0.01	0.05	0.06	0.35
•	$85 \times 165 = 0.56$	0.16	-	0.25	-0.06	0.01	0.03	0.04	0.31
85DMS6	850MS7 = 0.36	0.08	0.08	0.41	0.03	-	0.04	-	0.33
•	DMS1578 =0.31	0.16	0.06	0.41	-	-	0.03	-	0.19
•	DMS125C2=0.62	0.10	0.05	0.20	0.01	-	0.01	-	0.19
•	DMS13A = 0.39	0.10	0.08	0.36	0.02	-	0.04	-	0.31
85DMSR28	DMSR22 = 0.12	0.18	0.08	0.52	0.03	-	0.05	0.02	0.19
-	0MSR30 = 0.22	0.16	0.08	0.45	0.02	-	0.05	0.02	0.20
•	DMSR31B =0.54	0.12	-0.02	0.29	-	-	0.04	0.02	0.16
850MSH1010	MSH1018 =0.82	0.04	-	0.17	-	-	0.01	0.01	0.01
-	MSH101C =0.46	0.08	0.05	0.35	0.03	-	0.03	-	0.03
850MSD68A	DMS048A =0.32	0.15	0.05	0.41	-0.01	0.01	0.04	0.03	0.07
85DMSK10	DMSK2 = 0.21	0.21	0.07	0.43	0.02	-	0.03	0.01	0.01

# TABLE 4.4: Least squares modelling of proposed fractionating assemblages responsible forthe major element variation between clusters.

INITIAL LIQ	RESIDUAL LIQ	OLIVINE	CPX	PLAG	MAG-USP	APATITE	BIOTITE	ILMENITE	"FIT"
850MS6	84A11B' = 0.14	0.16	0.09	0.53	0.02		0.05		0.31
-	84A11C = 0.22	0.15	0.07	0.48	0.01	-	0.04	-	0.18
-	MSH1010 = 0.38	0.14	0.05	0.38	-	-	0.03	-	0.20
•	DMSR28 = 0.97	-	-	0.04	-0.02	-	-	-	0.004
•	DMSD68A = 0.27	0.14	0.07	0.45	0.01	-	0.04	-	0.24
-	DMSK10 = 0.87	-0.01	0.01	0.12	-0.01	-	0.01	-	0.18

observed well-developed plagiolcase lamination and rare macroscopic layering.

### 4.2.2 TRACE AND INCOMPATIBLE ELEMENT CHEMISTRY

Inferences from major element chemistry suggest plagioclase, followed by olivine, dominated the fractionation process. Plagioclase has a distribution coefficient  $(K_n)$  greater than one for Sr. This is demonstrated by the positive correlation between Sr (in ppm) and alumina in Figure 4.4b, although the Huntsville rocks lie below the main trend. Nickel substitutes for Mg in olivine and as a result the less evolved rocks contain higher Ni contents (Fig. 4.4f). However the variation within more magnesian intrusions is much greater than the variation in more evolved bodies, suggesting the initial liquids in the latter examples were nickel. This supports olivine already considerably depleted in fractionation prior to emplacement of the more evolved metagabbro bodies. Clinopyroxene fractionation would deplete the liquids progressively in chromium. This is not observed and on a Cr vs. CaO plot only the Huntsville rocks show a moderate positive correlation, possibly reflecting some clinopyroxene fractionation.

There is a good positive correlation between the highly incompatible elements Ba and  $K_2O$  (Fig. 4.4d), both preferentially enriched in the more evolved samples. Zircon is normally a moderately incompatible element but the presence of zircon and baddeleyite in interstitial areas (mesostasis areas effectively have a  $K_0$  of one for all elements) and sodic plagioclase rims, suggests Zr was becoming compatible in the residual liquids. However, because it is incompatible throughout most of the fractionation process, it is used as a frationation index for comparison with other major and trace elements in Figure 4.4e-h. There is a good negative correlation with the Mg number and Ni content, and a positive correlation with Ti, K, P, and other incompatible elements such as Ce, Y (Fig. 4.4h) and Nb. As expected there is no enrichment of Sr with Zr which supports a progressive loss of Sr while other incompatible elements became enriched.

The incompatible element abundances can be compared by normalising to the primordial mantle compositions of Wood et al. (1979). The proposed parental liquids are shown on Figure 4.5a and samples from the Fe- and Mgrich clusters in Figure 4.5b & c. The elements are arranged approximately

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FIGURE 4.4: Major and trace element diagrams for metagabbros in the CGB.



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FIGURE 4.5: Primordial mantle normalised incompatible element diagrams "spidergrams" for selected CGB metagabbros; normalising data from Wood et al. (1979).



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in order of increasing incompatibility from Y to Rb. Thorium abundances are low and absolute values obtained by the XRF should be treated wih (Appendix II). In general the patterns are gently dipping from Nb caution to Ti. but show variable enrichment in Ba, K, Sr and sometimes Thorium? The major difference between different clusters is the lower absolute abundances in magnesian samples (Figs. 4.5a & 4.9) which is consistent with the more evolved nature of the Fe-rich liquids. There is commonly a small Nb anomaly but this is minor and much less than the characteristic Nb anomaly of early Proterozoic and Archaean Dykes (Sheraton & black, 1981; Weaver & Tarney, 1987 in press). Strontium generally exhibits a positive spike, but this becomes less marked in the more evolved liquids where the remaining incompatible elements are enriched. The absolute Sr abundances are similar throughout the CGB, but plagioclase accumulation allows Sr to be enriched relative to the other incompatible elements in the magnesian clusters.

In terms of tectonic setting the primordial mantle normalised plots are similar to those of continental flood basalts (Thompson et al. 1983), and the mid-crustal dykes and sills inferred to be feeders to higher level, possibly extrusive flood basalt provinces (Weaver & Tarney. 1983); i.e. slightly enriched in large ion lithophile (LILs), light Rare Earth elements (LREEs) and more enriched in more incompatible relative to less incompatible elements. In continental basaltic magmatism there is always the possibility of crustal contamination and the moderately high Ba  $\pm$  Th could be a reflection of this. However this can also be explained by the breakdown of phlogopite during melting in the source area. The genesis of the CGB liquids and their relationship to other mid-Proterozoic basaltic provinces are discussed further in the next section.

## 4.3 COMPARISON WITH OTHER MIDDLE PROTEROZOIC BASALTIC PROVINCES

In this section the least-reacted metagabbros and proposed parental liquids from the Central Gneiss belt are compared with analyses from other basic intrusions of probable similar age from the Adirondacks (Whitney, pers comm.), Greenland (Upton & Thomas, 1980), central Labrador (Meyers & Emslie, 1977), and dykes cutting the Nain anorthosite in northern Labrador (Wiebe, 1985). In each case the primary mineralogy is equivalent to metagabbros from the Central Gneiss Belt. The geochemical similarity between

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basic intrusions from Greenland and Labrador was noted by Wiebe (1985) and furthermore, Emslie (1978) suggested the latter was a reflection of the waning phase of anorogenic magmatism responsible for the anorthosites. With the exception of the Adirondack material, not one of the other dykes provinces has undergone metamorphism and many are high level intrusions with chilled margins that contain phenocrysts in a fine-grained groundmass. The location of the various dyke suites are shown in Figure 4.6a together with other mid-Proterozoic mafic dykes and plateau basalt provinces in the Canadian Shield (Baragar, 1977).

Major element analyses of the Adirondack metagabbros were provided by P. Whitney (pers. comm). The gabbros are in the form of dyke or sill-like bodies and intrude anorthosite at Jay Mountain, the latter probably emplaced around 1288 Ma. (Ashwal & Wooden, 1983). The metagabbros show subsolidus corona-forming reactions (Whitney, 1973; McLelland & Whitney, 1980) similar to the gabbros within the Central Gneiss Belt. They represent the most Mg-rich and P.Ti-poor compositions (Fig. 4.7) and plot furthest into the tholeiitic field on the alkalis vs. silica plot (Fig. 4.2f).

The Harp dykes of central Labrador have a minimum K-Ar age of  $1316\pm$  194 Ma. Chemically they resemble other middle Proterozoic basaltic suites in Labrador (Meyers & Emslie, 1977) such as the Seal Lake Group (ca. 1350 Ma.), the Michael Gabbros (ca. 1426 Ma.) and the Mealy Mountains Complex (ca. 1350 Ma.). The Harp dykes lie north of the Grenville Front whereas the other examples lie partly or wholly within the Grenville province. Mineralogically the Harp dykes contain plagioclase, olivine and subophitic to poikilitic clinopyroxene which is weakly mauve in colour and has a titaniferous composition (1-1.6 Wt.1 TiO<sub>2</sub>). Olivine is intermediate in composition, up to Fo<sub>59</sub>. Accessories include opaque oxides, biotite and apatite.

The basic dykes cutting the Nain anorthosite of northern Labrador have been dated at ca. 1290-1042 Ma., the latter representing a minimum K-Ar age (Wiebe, 1985). They all exhibit similar major element chemistry and contain olivine of composition  $Fo_{51-47}$ . However they have been subdivided on the basis of structure and trace element character, into two distinct types: a more abundant N-S trending set containing much higher concentrations of incompatible elements, known as the HP dykes, and an ENE-WSW trending set referred to as the LP dykes. Both contain pale violet

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FIGURE 4.6a: Distribution of mid-Proterozoic gabbroic and alkaline magmatism (from Baragar, 1977).



FIGURE 4.6b: Hypothetical position of a pre-Grenvillian rift (from Baragar, 1977); Greenland restored to its pre-drift position.



titanaugite but it is more deeply coloured in the HP dykes (Wiebe, 1985). In addition the HP dykes contain greater amounts of olivine, opaque oxides, apatite and biotite. These dykes are unmetamorphosed but biotite occurs as rims around olivine and opaque oxides suggesting either cooling or late magamtic reaction/precipitation from a residual fluid enriched in  $K_2^0$ .

The Tugtutôq Giant Dyke Complex in Greenland is divided into two suites: an older Giant Dyke complex (OGDC) and a younger (YGDC) complex (Upton & Thomas, 1980). They were emplaced around 1170 Ma. (Van Breemen & Upton, 1972) and it has been proposed that they represent the highest level representatives of a large basic complex at shallow depths which gives rise to an extensive, linear gravity high. The Younger Giant Dykes (YGDC) are more abundant and most analyses come from this suite. Both suites evolve through a great range of magmatic differentiates, but the OGDC liquids always remained critically undersaturated and eventually gave rise to feldspathoidal syenites, whereas the YGDC although initially just nepheline normative, produced quartz syenites and granitic segregations containing only rare, late-stage alkaline veins. The YGDC are dominated by olivine-plagioclase with lesser amounts of clinopyroxene, ilmenite, Timagnetite, biotite and apatite. Olivines range in composition from Fo<sub>cs</sub> to Fo<sub>in</sub>. The chilled marginal suites contain phenocrysts of olivine and plagioclase, the latter being modally more abundant.

### 4.3.1 MAJOR ELEMENT VARIATION

The major element variation diagrams are given in Figure 4.7 and the normative fields are included in Figure 4.1. As before, most samples contain high normative olivine, either just within the undersaturated nepheline field or within the Ol-Di-Hy triangle. The only exceptions are several quartz normative analyses from the Harp dykes of central Labrador (Meyers & Emslie, 1977). On an alkalis versus silica diagram (Fig. 4.2f) all the analyses plot in the transitional area between tholeiites and alkali basalts. On the AFM diagram (Fig. 4.3) they lie broadly on the tholeiitic trend. In the major element diagrams (Fig. 4.7) the complete range of CGB analyses overlap analyses from each dyke suite (with the exception of phophorous), but only the field of proposed primary CGB liquids are delimited.

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FIGURE 4.7: Major element variation diagrams for several areas of mid-Proterozoic basaltic magmatism in the Canadian shield and Greenland (key in Fig 4.7g; for Fig. 4.7h refer Fig. 4.8).



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On an  $Al_2O_1$  vs. SiO<sub>2</sub> variation diagram (Fig. 4.2b & 4.7a) the CGB, Adirondack, Greenland and LP data show the positive correlation consistent with plagioclase fractionation. In addition, least-squares modelling of major elements reported by Upton & Thomas (1980) suggest that the liquid evolution for the Tugtutôq Giant Dyke Complex was controlled by similar amounts of olivine and plagioclase fractionation (each contributing approximately 30%). However the Central Labrador and HP dykes of northern Labrador show negative trends that imply plagioclase was not an important component in a fractionating assemblage. Instead olivine and clinopyroxene may have been the controlling phases and in Figure 4.7d the HP and Harp dykes show a positive correlation, consistent with clinopyroxene fractionation. The minor elements titanium, potassium and phosphorous, are plotted against Mg number in Figures 4.7e,f & g. The high phosphorus contents of the Greenland and HP dykes differentiates them into individual groups. Note the change in gradient around 0.35 M/FM when the HP and Greenland dykes become enriched in both phosphorous and potassium.

#### 4.3.2 TRACE ELEMENT VARIATION

There are no trace element data available for the Adirondacks or Harp dykes so only the Greenland and Nain dykes are compared with analyses from the CGB. On a Ba vs.  $K_2$  0 plot (Fig. 4.7h) the Nain dykes are similar to the CGB samples, but the Greenland samples define two separate. Ba-rich, positive incompatible enrichment trends. On a Sr versus Al<sub>2</sub>O<sub>3</sub> plot (Fig. 4.8a) there is a poor to slight positive trend within each suite but more importantly, all the dykes lie at very different levels of Sr enrichment. This suggests an independent source for each suite. Rubidium is enriched in the Nain and Greenland dykes, especially the HP and YGDC suite (Fig. 4.8b,d), whereas Ba and Sr are only enriched in the Greenland dykes. Thus the Rb/Sr is much higher in the Nain HP dykes.

Trace element variation diagrams with Zr as a common fractionation index are given in Figure 4.8c to g. Zirconium does not become enriched until the Ni content falls below  $\sim$  150 ppm (Fig. 4.8e). This is analogous to the trend within the CGB suite (Fig. 4.4e). On plots of K<sub>2</sub>O vs Zr and Rb vs. Zr (Figs. 4.8c & d) all the dykes plot in different fields, each showing a positive correlation (apart form the Zr-rich HP dykes), thus implying distinctly different source characteristics. Furthermore, the HP dykes deviate from the Zr/Y gradient (defined by the fields in Fig. 4.8g)

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FIGURE 4.8: Major and trace element diagrams for mid-Proterozoic dyke suites.



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and this suggests that Y is being retained preferentially to Zr in the source. This may be a reflection of increased clinopyroxene fractionation that depleted the liquid in Y. This was proposed by Wiebe (1985) to explain the variation of Sr and CaO with MgO (the latter outlined in Figure 4.7d). Thus, as suggested earlier, the HP liquids apparently had clinopyroxene as well as olivine, as an important fractionating phase. On a Ce vs. Y plot (Fig. 4.8h) the HP and Greenland dykes define two separate trends that are different from the CGB analyses. As before, this suggests distinctly different primary liquid compositions.

Primordial mantle-normalised diagrams ("spidergrams") are presented in Figure 4.9. In general, varying amounts of fractional crystallisation and partial melting will change the levels of the patterns (with the possible exception of Sr and Ti), whereas the source characteristics and various enrichment processes change both the level and the shape of the normalised diagrams (Pearce, 1983). All the dyke suites were apparently derived from similar subcontinental source areas, but show variable enrichments in incompatible elements. The patterns for Greenland and HP dykes are broadly similar and much more enriched than the CGB samples. The normalised adundances for the LP dykes, apart from the positive Zr spike, are most like the Fe-rich CGB rocks. The HP liquids are considerably more have a negative Sr anomaly suggesting depletion by but enriched plagioclase fractionatin prior to intrusion. However the Rare Earth element (REE) plots presented by Wiebe (1985), lack a significant negative Eu anomaly and instead he proposed that olivine and clinopyroxene were major fractionating phases. If so strontium may never have been enriched relative to the other incomaptible elements.

Both Greenland dyke suites have similar incompatible element patterns with very high Ba contents (Fig. 4.9c & d). Upton & Thomas (1980) proposed that the deep level liquid evolution was dominated by olivine, clinopyroxene and possibly garnet fractionation, while higher level (<10 Kbar) fractionation involved olivine and plagioclase. In addition they suggested that although the source for both dykes had similar characteristics (i.e. depleted in Rb and enriched in Ba,Sr), the differences in absolute abundances of Ba,La,Ce,Sr,P and Ti between suites could not be accounted for by different degrees of fractionation or partial melting. Instead they suggested that the source for the OGDC liquids was preferentially enriched in Sr,Ba,P and Ti, unless a more complex fractionating assemblage, perhaps involving apatite and phlogopite, is invoked.

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FIGURE 4.9: Primordial mantle normalised "spidergrams" for various mid-Proterozoic dyke suites (refer text). The field for Fe-rich and Mg-rich parental liquids in the CGB has been superimposed.



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### 4.4 DISCUSSION

The middle Proterozoic dykes have a continental basaltic character, transitional between tholeiites and alkali basalts. Continental basaltic magmatism has been attributed to derivation from enriched subcontinental sources from where liquids are subjected to varying amounts of crustal contamination during ascent (Weaver & Tarney, 1983; Thompson, 1983). The amount of enrichment is reflected in the abundance of incompatible elements but complications arise because complex fractionating assemblages, other than olivine, clinopyroxene, garnet or spinel, are possible and include apatite, phlogopite, ilmenite and possibly Zr-bearing These can also act as residual phases during low degrees of minerals. partial melting, preferentially retaining K,P and Ti in the source. As a result they can exert considerable control on the liquid composition and make interpretation difficult.

All the mid-Proterozoic dykes described here are high in normative olivine and the mineralogy includes olivine of intermediate composition. plagioclase, oxides, varying amounts of titaniferous clinopyroxene and accessory biotite. There are no isotopic data available but the early evolution of the CGB and other dyke suites may have involved varying amounts of partial melting and fractionation in similar subcontinental source areas. The primary magma compositions are highly speculative but it is likely that during ascent plagiolcase, olivine  $\pm$  clinopyroxene and the minor phases apatite and phlogopite were fractionating. After emplacement the major and trace element variation of the CGB gabbros was controlled by plagioclase and lesser olivine fractionation.

The trace element variation and primordial mantle normalised diagrams highlight the considerable differences between the dyke suites, especially in the abundances of Ba and the LILs and to a lesser extent P, Zr and Ti. This represents distinct differences between the dyke provinces and reflects variations in the source and evolutionary pathways for the corresponding parental liquids. The LP dykes in Nain are most like the CGB metagabbros whereas, the most enriched incomaptible element patterns come from the OGDC dykes of Greenland. The HP dykes of Nain are similarly enriched but are characterised by a negative Sr anomaly, although only a small Eu anomaly. As a result the relative Sr-depletion may have been a function of selective source enrichment processes; i.e. the absolute Sr abundances are similar in both the HP and LP dykes, but the other

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incompatibles are considerably more enriched in the former.

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The enrichment in most incompatible elements especially Ba (Th data is only available for CGB gabbros), could be partly caused by variable amounts of crustal contamination. It could also be a reflection of preferential enrichment of magmas in the most incompatible elements during higher degrees of fractional crystallisation. The latter process can account for the small differences between the more magnesian and Fe-rich suites of the CGB. However it is unlikely that either can account for the large differences in absolute abundances between the various dyke Instead considerable variations in the amount of enrichment in provinces. the subcontinental source are more likely. Indeed, Upton & Thomas (1980) suggested primary source differences for the OGDC and YGDC liquids, although some fractional crystallisation of apatite and phlogopite during the evolution of the YGDC liquids, could account for the differences. However the latter process cannot explain the even larger differences between the Nain, CGB and Greenland dykes and again variable enrichment in the mantle source region appears to be the most likely explanation. Thus the dykes although superficially similar, have some distinctly different source characteristics.

Other mid-Proterozoic alkali to transitional basaltic dykes include the Group III dykes of the Beartooth Mountains in Montana and Wyoming (Mueller & Rogers, 1973). These have been dated at ca. 1227  $\pm$  77 Ma. and contain olivine, titanaugite, plagioclase and Ti-magnetite. No chemical analyses were listed by the authors, but they have a Rb/Sr ratio similar to that of the HP dykes in Nain province. There is also a suite of dykes east and southeast of Sudbury, northwest of the Grenville Front in SW Grenville Province. These are the Sudbury Dykes of Palmer et al. (1977) emplaced ca. 1250 Ma. Again no systematic chemical analyses were given but they contain titaniferous augite and primary biotite in addition to olivine-plagioclase. They have high Ba contents (600-800 ppm) comparable to the HP and YGDC dykes described above. It has been proposed that they have metamorphic equivalents reworked within the Grenville Front Tectonic Zone and the latter show some mineralogical similarities to metagabbros within the CGB, including rod-like inclusions of ilmenite in relict primary clinopyroxene and cores of relict plagioclase laths clouded with fine dust. The Sudbury dykes may represent the southern continuation of the extensive MacKenzie dyke swarm (Fig. 4.6). In addition the Keweenawan basalts, southwest of Lake Superior, are tholeiitic to transitional

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plateau basalts and represent magmatism in a Precambrian rift which developed between 1.15 and 1.0 Ga. The rift forms a mid-continent gravity high which extends southwest into Kansas (Chase & Gilmer, 1973). Bickford et al. (1986) suggested that the rift may be related in a broad sense to the Grenvillian orogeny and Windley (in prep.) proposes an analogy with the Rhine Graben which formed during the Alpine orogeny. The MacKenzie and Sudbury dyke swarms are approximately perpendicular to the trend of the Keweenawan rift, but are approximately parallel to the transforms which offset it.

Thus the North American craton apparently underwent considerable crustal extension during the middle Proterozoic (ca. 1.5-1.2 Ga, or until 1.0 Ga. in the Keweenawan rift). Baragar (1975) presented a hypothetical rift zone that connects magmatism in southern Greenland and Labrador with the Keweenawan rift, taking into account an offset by a transform (Fig. 4.6b). The proposed rift lies wholly within the Grenville province and through a cluster of alkaline intrusions. It predates the passes culmination of Grenvillian deformation and as a result, does not take into account the northwest-directed thrusting and crustal shortening during the latter stages of the Grenvillian orogeny. Baragar (1975) also proposed three high level basaltic provinces (Labrador-Greenland, that the Keweenawan and Coppermine River Flows, Figure 4.6a) represented mantle plumes around which the loci of corresponding basaltic dykes converged. The CGB metagabbros are the only evidence of tholeiitic to transitional magmatism in the CGB of SW Grenviile province and it is possible that they are the lower crustal remnants of magmatic activity that later gave rise to the plateau basalts in the Keweenawan rift. Thus they reflect extension in the foreland prior to collision and subsequent thrusting and crustal thickening.

### 4.5 ANORTHOSITIC ROCKS

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In the Central Gneiss Belt the anorthositic material ranges from leucogabbro (65-901 plagioclase) to anorthosite sensu stricto. In each case, the field relations are consistent with a tectonic emplacement by break up of large, layered complexes or anorthosite massif(s) at depth (Chapter 3. section 3.2). The largest anorthositic bodies crop out in the Parry Sound Shear Zone (PSSZ) along the northwestern margin of Parry Sound

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domain. However this section concentrates on the geochemistry of smaller bodies to the south. These take the form of small tectonic inclusions or laterally continuous lenses within migmatites, granulites and orthogneisses. The mafic minerals include opaque oxides, hornblende, rare orthopyroxene and epidote; scapolite is a common alteration product of plagioclase. The Go Home examples (Fig. 3.2) are interlayered with highly strained mafic gneiss which may represent part of the original igneous stratigraphy. It appears that strain was taken up preferentially in the more ductile mafic rocks and at one low-strain locality (84DMS-134), the anorthosite is preserved in the form of relatively undeformed coronite leucogabbro. Here a primary orthopyroxene core has been replaced by anthophyllite-actinolite and rimmed by hornblende and garnet.

The anorthositic samples described here come from Go Home and Rosseau subdomains and the boundary shear zones between Moon River-Go Home and Huntsville-Novar subdomains (Fig. 3.1). These are compared with leucogabbros from Go Home. Rosseau and highly strained samples from the Whitestone anorthosite in the PSSZ. In addition a few mafic lenses adjacent to or included within the anorthositic gneiss are plotted for comparison to see if they could be basic representatives of the anorthositic magmatism. In terms of normative components the anorthosites leucogabbros define separate trends from the gabbroic dykes described and in section 4.4 (Figure 4.1a), i.e. at higher values of the D.I for similar normative An/An+Ab. The anorthosites cluster around An S0-65 while leucogabbros range from An 55-76. The anorthosites are low in mafics but are nearly always nepheline-normative, whereas the leucogabbros and mafic rocks straddle the Di-Ol join in the Ne-Ol-Hy-Di quadrilateral at moderate to high normative olivine contents. Mafic lenses plot on a different trend from the anorthosite-leucogabbroic suite on Figure 4.1a, at lower values of the Differentiation Index and straddle the fields for Proterozoic dykes. In Harker diagrams (Fig. 4.10 a-e), the mafic rocks lie broadly on the anorthositic trend and are the most enriched in Fe, Mg, Ti and in alkalis and alumina. The only exception is the poor depleted correlation in Figure 4.10d where CaO is plotted against silica. This presumably reflects the competition between greater proportions of mafic (pyroxene or hornblende) in the leucogabbroic rocks and minerals increasing amounts of plagioclase accumulation in the anorthosite. On a Ca0 vs Mg0 plot (Fig. 4.10f) there is no correlation which implies clinopyroxene fractionation was not important.

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In terms of incompatible elements the anorthosites are highly depleted in La,Ce,Zr,Ti,Y and the normalised abundances become progressively more enriched from leucogabbros through to mafic samples. This is consistent with the interpretation of the anorthosites as extreme plagioclase cumulates and in no way can they represent liquid compositions. The Sr abundances are variable but highest in the anorthosites and decrease slightly in the leucogabbros and mafic rocks (Fig. 4.10g). On Y vs. TiO2 and Ce vs. Y plots the mafic samples define a seperate field (Fig. 4.10h) and do not appear to be related to the leucogabbros by varying amounts of fractional crystallisation. The mafic rocks are also considerably different from the coronite metagabbros and may represent another, independent magma association.

Thus the anorthosites and leucogabbros in the Central Gneiss Belt plagioclase cumulates which formed as part of represent larger intrusion(s) at depth. During thrusting tectonic lenses of anorthositic material were caught up in the deforming gneisses. The Parry Sound anorthosite has been dated at 1350 Ma. (Van Breemen et al., 1986), while massif-type anorthosites in the Adirondacks, Nain and Grenville range in age from 1600 to 500Ma, although most range from 1500-1400 Ma. In the Adirondacks, the Marcy anorthosite was probably intruded around 1288Ma. (Ashwal & Wooden, 1983). It is characterised by LREE enrichment and a positive Eu anomaly and as the content of mafic minerals increases, the level of REEs relative to Eu increases resulting in a relative decrease in the Eu anomaly (Ashwal & Seifert, 1980). This supports the hypothesis that leucogabbro to anorthosite represents increasing the trend from accumulation, although complications arise from varying plagioclase amounts of trapped liquid (Ashwal & Seifert, 1980).

It has been suggested that the parental magma to the anorthosite is a high-alumina tholeiitic basalt, rich in normative plagioclase (Ashwal & Seifert, 1980; Morse, 1982: Wiebe, 1986). In addition, isotope and whole rock &Nd data from the Adirondacks (Ashwal & Wooden, 1983; Basu & Pettingill, 1983) imply that the mantle source for the parental magma was depleted in LREEs. The model proposed by Emslie (1978) and Morse (1982) for the subsequent liquid evolution involves olivine tholeiitic magma ponded at or near the base of the crust where it underwent extensive fractional crystallisation of olivine and pyroxene, prior to saturation with plagioclase. In addition Wiebe (1986) described nodules consisting of plagioclase and high Al-opx in the HP and LP dykes cutting the Nain

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anorthosite. He suggested these nodules came from the lower crust and were part of the suite of lower crustal cumulates complementary to the anorthosite which survived because of rapid transport to the upper crust during the basaltic magmatism. The tectonic setting of the anorthositic magmatism is equivocal, but again it is generally thought to be extensional in an anorogenic continenetal rift (Emslie, 1978). If this were the case, the extensional magmatism in the North American craton probably extended back to 1500 Ma.

### 4.6 CONCLUSIONS

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- 1) The basaltic magmatism in the Central Gneiss Belt has a continental character, transitional between tholeiites and alkali basalts. The evolution of the parental liquid between various cluster of gabbroic rocks is compatible with the dominance of plagioclase in the fractionating assemblage. The magmatism may be part of a broader zone of extensional, tholeiitic activity in mid-Proterozoic times, each exhibiting similar major-element characteristics, although trace element data confirm similar, but variably enriched mantle sources for the magmatism.
- 2) The anothositic slivers in the CGB represent tectonic fragments of plagioclase cumulates. The majority of large anorthosite massifs in the northeast Grenville Province, Labrador and Greenland generally predate the spatially-related basaltic magmatism, but may also have formed in the extensional setting of an anorogenic rift.
- 3) As a result of 1) and 2), it is likely that a large part of the Canadian Shield underwent extension during Mid-Proterozoic times (1.5 to 1.2 Ga.). In the southwest Grenville Province, the mid- to lower crustal expression of this magmatism was exposed by subsequent thrusting and crustal thickening during the culmination of the Grenvillian orogeny.

The following Chapters discuss both qualitative and quantitative estimates of the physical conditions of metamorphism that prevailed in the crust during and after emplacement of the gabbros. In doing so a P-T path has been constructed for the latter stages of the Grenvillian orogeny, both before and during collision and post-collisional convergence, the latter probably being responsble for the thrusting in the Central Gneiss Belt.

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# CHAPTER V

# THE HOST GNEISSES: MINERALOGY AND PHYSICAL CONDITIONS OF METAMORPHISM

### 5.1 INTRODUCTION

This Chapter discusses the compositional variation within gneisses from the southwestern Central Gneiss Belt (CGB) and attempts to estimate the prevailing metamorphic conditions during the culmination of the Grenvillian orogeny (ca. 1.1-1.0 Ga.). The mineralogy and P-T estimates are considered within the tectonic framework outlined in Chapters 2 & 3, thus highlighting if any differences in metamorphic grade exist within or between subdomains. Furthermore, the metamorphic conditions represent the external controls on reactions in metagabbroic rocks and these are the topic of Chapter 6. The dominant lithologies comprise quartzo-feldspathic and migmatitic orthogneiss; granulites; metasediments including pelites, semi-pelites, calc-silicates and marbles; amphibolites; ultramafics and anorthositic gneiss. Large areas are covered by relatively homogeneous and undifferentiated migmatites and granulites that probably represent a reworked, pre-Grenvillian basement derived from predominantly igneous precursors. There are also a number of sapphirine occurrences and these are considered separately in Chapter 8.

### 5.2 PETROGRAPHY

This section discusses the textures and mineralogy of samples from the host rocks and is subdivided into the common lithologies.

### 5.2.1 AMPHIBOLITE FACIES GNEISS

Migmatitic and banded gneisses constitute most of Muskoka domain although it also includes several areas of relict granulite facies assemblages (Fig. 2.4). The gneisses range from quartzo-feldspathic to mafic in composition and are commonly migmatitic with pink, quartzo-

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feldspathic leucosomes which may or may not be foliated. The assemblages are listed in Table 5.1 and the main mineralogical variations are represented by the presence or absence of amphibole and garnet. The rocks have undergone varying amounts of strain and the textures vary from granoblastic-decussate to sheared and mylonitic, where flattened and polygonised quartz ribbons define the foliation (Plate 5.1a).

### 5.2.2 GRANULITES

In the classic work on the amphibolite to granulite facies transition in the Adirondacks (Engel & Engel, 1962), clinopyroxene in amphibolites was succeeded initially by two-pyroxene granulites and then by garnet-bearing granulites at slightly higher grades. Thus in rocks of similar bulk composition the presence or absence of garnet in granulites reflects different grades of metamorphism. In the CGB, granulite facies assemblages dominate in Parry Sound and Algonquin domains (refer Fig. 2.4), while in the Kawagama shear zone, between the Algonquin and Muskoka domains (Fig. 3.10), there is a mixed association of granulite and gneiss. In addition, leucocratic granulites or facies amphibolite charnockites are present in the dominantly amphibolite facies subdomains in the neck of Seguin subdomain (Nadeau, 1985) and south of the Kawagama zone. The major mineralogical variations are represented by the presence or absence of K-feldspar, biotite, garnet, clinopyroxene and amphibole (Table 5.1). Mafic granulites are characterised by two pyroxene + garnet mineralogies, garnet notably uncommon in Opeongo subdomain (Table 5.1). Amphibole and biotite are present in small amounts as part of the equilibrium assemblage and amphibole varies from yellow to olive green and Many samples have undergone extensive retrogression involving brown. almost complete replacement of pyroxene by amphibole + biotite. However, well-equilibrated granoblastic two pyroxene-garnet granulites are still common (Plate 5.1b) and indicate closure to retrogression.

### 5.2.3 METASEDIMENTS

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 Recognisable paragneiss is not common in this part of the CGB. However it does occur and useful petrogenetic assemblages are represented by aluminosilicate-bearing pelitic gneisses, marbles and calc-silicates. Other metasediments include quartzites, semi-pelites and well banded,

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GNEISS	QTZ	K-FSP	PLAG	BIGT	AMP	GT	OP	AP	СРХ	MUSC	ZR	SPH	EPIO	Comments
Go Home	 X	×	 X	х Х	****	x	 X	×	*****					
	x	x	X	X	X	x	X	X				X		Mafic
	X	X	X	X	X		X	X		X	X			м
	X	X	X	X								X		
Opeongo	x	x	X	X		X	X				X		X	QF Gneiss
	x	x	х	х	х		x	х			x		X	
	x		x	x	x			X	x		x			
ı			X	X	x		x	x						
	x		x	X	x		X	X						
Hunteville	X	x	' <b>X</b>	Y		x		Ŷ			x			
	x	Ŷ	Ŷ	Y	¥	Ŷ	¥	Ŷ						
	Ŷ	Ŷ	Ŷ	Ŷ	Ŷ	Ŷ	Ŷ	Ŷ	¥		x			
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<b>D</b>	X		×	х 	X	X	X	X 	X					
Hosseau	X	X	X	X	X		X	X	X					
	X	X	X	X		X								
PSSZ	X	X	x	x	X	X	X							
GRANULITES	QTZ	K-FSP	PLAG	BIOT	AMP	GT	۵P	٨P	СРХ	OPX	ZR	Commo	ent	
Ga Home	 X	*****	 X	×		 X	×		×	×		Mafi	c	
			x		x		x	x	X	x				
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	Ŷ	Ŷ	Ŷ	Ŷ	Ŷ	Ŷ	^	Ŷ	¥	x	x			
	^	^	Ŷ	Ŷ	Ŷ	•	Y	Ŷ		x	x			
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Seguin	×.	*	× v		Ň	v	Ŷ.	v	v	Ŷ	^	GINE!'I		
nuntsville	X		X	v	X	X	X V	, A	^	Ŷ				
	X	X	X	X	X	X	X	X	v	, V				
	X	X	X	X	X	X	X	X	×	×				
	X	x	X	X	•	X	X			X V		M. 41	_	
_			X	X	X	X	X	X	X	X		matic	•	
Rosseau	X	x			X	X	X		X	X				
			X	X	X	X	X	X	X	X				
Parry Sound	X	X	X		X		X		x	X				
	X		X	X	X	X	X	X	X	X				
	X		X	X	X	X	X			X				
Kawagama	X	x	X	X		X	X			X		Charr	nocki	te
-	x	x	x	x		X	X			X				
			X		x	X		X	x	X		Mafic	:	
	x		x		x	x	X		X	X		н		
	X	x	X	x		X	x		x	x		**		
	^													

# TABLE 5.1: Common mineral assemblages within the CGB.

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TABLE 5.1 (c)	ont'd)																
PELITIC GNEI	SS QTZ	K-FSP	PLAG	BIOT	AMP	GT	OP	AP	СРХ	(OP)	X SI	LL	KY 1	IUSC	ŻR	SPH	Comment
Go Home	x	x	x	X		x	x				x					* =	
Opeongo	X	x	X			X	X(G)						x			X	
luntsville	X	x		X		X	X(G)										
	X	x	X	X		X	X(G)						x				
	X	x		X		X											Meta-quatzite
	x	x	X	X	X	X	X	X	X							x	•
		x	X	X		X		X							x		
Rosseau	x	X	X	X	X	x	X	X	X							x	
PSSZ	x	x		X		x	X(G)								X		
	x		X	X		х	X						X	X			
Parry Sound	X ·		X	x		x					x						
Cawagama	x	x	X	X		x	X			۰ <b>x</b>							
	X	x	X	X			X(G)		X								
IARBLE	QTZ	K-FSP	PLAG	BIOT	AMP	GT	0P -	AP C	PX S	РН	CC	WOL	L SC	AP	ZR	VES	Comment
ia Home		 X	An29	*****		 X			 X		 X				x		Marble
	X	X	X				x		x		X						
		X	x				x		x	x	••						**
	X	••	 4n26-3	29		X	x		x	••	x	¥	X				•
	~	¥	An25-1	29		x	**		x.		x		Ŷ			X	Marble incl
Jacobas	Y	•	**************************************	79		Ŷ	¥		n Y	Y	^		Ŷ			^	Skarn
-haouâo	^		×0.113 V	.0		Ŷ	Ŷ.	•	$\overline{\mathbf{v}}$	~			Ŷ		¥		
	Y 0	-00-07	^			^	^	<b>`</b>	~ ~	~	v	v	Ŷ		^		Marhle
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untout 11a	÷	^	v			Ŷ	*		~ •	~	÷.	v	Y		^		Marhle
	^	v	Ĵ	v	~	^	<b>.</b>			<u> </u>	Ĵ	Ŷ	Ŷ				Marble
		^	A V	X	×	~	× .	κ	х. И	*	Š.	^					Manhla
arry Sound			×			X			×		*						
AFIC & UH	PLAG	BIOT	AMP G	6T 0	P AF	, c	PX O	PX I	DL SI	P S	CAP	ZR	COR	RU	TS	SPH	Comments
ia Home	x	́х	x		x >	<b>(</b>						x					Amphibolites
	x	X	X	<b>(</b>	x )	<	X										*
	x	x	X X	<b>(</b> )	X												Anorthositic
	x		X		X												14
	x		X X	(													*
	x	x	x x	<b>(</b> )	x >	C	X										Coronite leucogab
peongo	X	X	x x	( )	x x	(											Amphibolite
luntsville					x		x x	X	x								UM; 50-60% 01
	x	x	x		x		X										UM; 10-20% Plag
		X	Y	( <sup>-</sup>	X		x x	x	x								Peridotite
	x		Ŷ				X Y	~									Retro Peridotite
	x	x	X Y		x		x x		Y	Y	<u>د</u>						
	Ŷ	~	Ŷ Ŷ						^	^	-						Pyroxenite
	Ŷ	Y	~ ~	` ,	v								Y				Anorthositic
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	^	Ŷ	× ×	, , ,			~ ×					^				~	Peridatite
Ubret		× v	x )		^		~ X 	X	X								11M
	v	X V	<b>.</b>	, .	х И		x X	X	X								Amohibolite
	X	X V	X X		Α.		A 2										н
	X	X	X				ĸ										*
	X	X	X		λ.												Aporthositic
	X	X	XX		K									X			M CHOREESE
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	X	X	X X						X				x				cor-sp knots
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• • -	X		x x	; )	C .	2	K							X			rseudo-eclogite
			<b>v</b> v	, ,			v v			~ ~	,		v				Leucogabbro
-222	X	X	XX	<i>د</i> ۲	•		~ ^				•		^				

compositionally heterogeneous gneiss. There are no staurolite-, cordierite- or chloritoid-bearing assemblages.

### Pelitic and semi-pelitic units

These commonly contain graphite (G in Table 5.1) and tend to weather to a rusty brown colour. Sillimanite is the dominant aluminosilicate polymorph, occurring in the form of relatively large prismatic crystals intergrown with biotite, garnet, quartz and feldspar (Plate 5.1c). Garnet associated with pelitic gneisses is typically bright pink in hand specimen, whereas garnet associated with intermediate gneissses and granulites is red to reddish brown, reflecting significant grossular in the latter. Kyanite has only been observed in association with sapphirine (Chapter 8) and in the Parry Sound Shear Zone (PSSZ) where it forms an equilibrium assemblage with garnet, muscovite, biotite, quartz and feldspar. This is the only area where muscovite is part of the stable equilibrium assemblage and suggests equilibration at lower temperatures, but not necessarily lower pressures, within the PSSZ; i.e below the muscovite breakdown reaction (Fig. 5.1). This is discussed further in the next section.

### Marbles and calc-silicates

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The marble assemblages listed in Table 5.1 include diopside, wollastonite, grossular and vesuvianite; there is no forsterite or tremolite, and plagioclase is commonly replaced by scapolite. Grossular occurs both as discrete grains and as narrow rims between several mineral pairs: between plagioclase and wollastonite (85DMSH-103A; Plate 5.2d), around scapolite (85DMSH-103A), and between calcite and plagioclase (84DMSA-161, 84DMS-91A and 85DMSP-4B), thus invoking reactions such as An + Wo  $\rightarrow$  Gr + Qtz and Cc + An  $\rightarrow$  Gt + Qtz. Furthermore in 85DMSR-41 and 84DMS-99B, scapolite and wollastonite are unstable with calcite.

Bouding of calc-silicate are found in various metasedimentary units including marbles, where they occur as green diopside-rich pods up to several centimeters in diameter. There is also an outcrop of granulitegrade skarn in Opeongo subdomain (Plate 3.2b) which contains large poikiloblastic garnets, bright green clinopyroxene, plagioclase altering to scapolite and a little quartz.

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# PLATE 5.1

A: Quartzo-feldspathic blastomylonite with polygonised quartz ribbons from a high strain zone structurally below the boudin of garnet peridotite (85DMSH-102) in Huntsville subdomain.

B: Two pyroxene-garnet granulite from Huntsville subdomain.

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C: Garnet, sillimanite-bearing pelite from Opeongo subdomain (840MSA-160).

D: Grossular rims around wollastonite in marble from Huntsville (subdomain (850MSH-103A).



FIGURE 5.1: Petrogenetic grid for assemblages within the Central Gneiss Belt (CGB) with estimated P,T conditions from the various subdomains superimposed. Aluminosilicate triple point after Holdaway (1971).



### Amphibolites

Amphibolites occur as layers and boudins within migmatitic (Plate 3.1a) and granulite facies gneiss. They commonly contain clinopyroxene, representing isograd 2 in the transitional granulite facies field of Engel & Engel (1962). In some samples clinopyroxene is mantled by discontinuous amphibole and separated from garnet by a plagioclase moat (Plate 5.2a). In hand specimen this results in a "garnet spotted" amphibolite which is also a common product from the textural reworking of coronite metagabbros (Chapter 6, section 6.2).

### Anorthositic gneiss

Tectonic inclusions of anorthositic gneiss are common throughout the CGB in SW Grenville province. They occur within subdomains and along the marginal shear zones where they can be traced discontinuously along tectonic strike for several kilometres (Chapters 2, 3). Compositionally they vary from anorthosite to leucogabbro and their whole rock geochemistry is discussed in Chapter 4. They are preserved in various stages of strain where plagioclase has typically recrystallised into a granoblastic mosaic while hornblende has replaced mafic minerals. However one Georgian Bay in Go Home sub-domain sample of leucogabbro from has retained a core of primary orthopyroxene partially (84DMSH-134A) by tremolite-actinolite and anthophyllite <u>+</u> chlorite, and replaced surrounded by a corona of hornblende and garnet (Plate 5.2b).

The major mineralogical variations are represented by the presence or absence of garnet, biotite, opaque oxides and pyroxene as well as modal variations in the proportions of plagioclase to mafics. Modal garnet varies from minor amounts (< 5%), present as small anhedral crystal within granoblastic plagioclase, to 10-20% in more mafic gneiss derived from leucogabbro. Scapolite is occasionally present as an alteration product of plagioclase.

In Rosseau subdomain the anorthositic gneiss includes mafic lenses, one of which contains sapphirine while another exhibits corundum-spinel "knots", presumably after sapphirine. This is discussed further in Chapter 8. There are also pods of "pseudo-eclogitic material (Davidson et al., 1982) where garnet ( $\sim$ 30%) is present as large anhedral porphyroblasts with inclusions of rutile, opaques and quartz. Here clinopyroxene ( $\sim$ 20%) forms

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### PLATE 5.2

- A: Relict "pseudoeclogitic" rock from Go Home subdomain (84DMS-518). Garnet is surrounded by a plagioclase moat and relict clinopyroxene has been almost totally replaced by hornblende.
  - B: Coronite leucogabbro (84DMS-134A) from Go Home subdomain. The corona is cored by rare orthopyroxene which has been replaced by actinolite, anthophyllite and chlorite and this is surrounded by hornblende and discontinuous garnet rims.
- C: Relict garnet peridotite from Huntsville subdomain (85DHSH-102C). A vermicular symplectite of orthopyroxene and spinel separates olivine
  and primary pyroxene from garnet.
- D: Evolved garnet peridotite from the same locality as above. Here reactions during decompression have resulted in the loss of olivine and relict garnet kernals surrounded by intergrowths of amphiboleplagioclase. Amphibole is also retrogressive on primary pyroxene.

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wormy, poikiloblastic intergrowths with plagioclase. This is a common texture in retrograde eclogites (Boland & Van Roermund, 1983), and in some of the sapphirine-bearing rocks from Arnstein (Chapter 8, Plate 8.2b) where the alumina content of omphacitic pyroxene has been exsolved as plagioclase. Clinopyroxene has also been extensively mantled by amphibole, and cpx<u>+</u>amph is now separated from garnet by a plagioclase moat.

#### Ultramafics

These range from olivine pyroxenites and dunites to garnet-bearing ol-pyroxenites or peridotites. They occur as boudins within enclosing granulite or amphibolite facies gneiss and have undergone varying amounts of hydration and in the case of gt-peridotites, decompression reactions.

The garnet-free pyroxenites contain between 0 and 60% olivine which is normally extensively altered to serpentine. Plagioclase ranges from 0-20% and primary ortho- and clinopyroxene have been variably replaced by amph<u>+</u>biot. Several samples also contain a few spinel grains (< 5%) and 85DMSR-39 is rich in magnetite (10-15%).

The gt-peridotites or ol-gt pyroxenites have been found at three localities (85DMSR-15, 85DMSH-102 and 85DMSD-10, Fig. 1.1). They each exhibit various stages in a decompression history from a primary assemblage involving ol-opx-cpx-gt-phlog-op+amph+chromite (Plate 5.2c), where primary modal proportions are masked by the initial decompression product of a pyroxene-spinel symplectite (Plate 5.2c). Olivine contributes approximately 10-30% and consequently they are not strictly peridotites. However, because they occur in a thrust belt they have been equated with Alpine-type peridotites. Approximate modal proportions of other phases are as follows: garnet 15-20%; pyroxene 20-40%; the spinel-bearing symplectite 10-20%; and phlogopite between 5 and 10%. Amphibole is mainly a retrogressive phase on mafic minerals although in 85DMSD-10B, it encloses orthopyroxene and may be primary.

The first reaction recorded in the peridotites was the formation of a spinel-pyx symplectite between garnet and either olivine or pyroxene (Plate 5.2c). Later reactions involved the corrosion of garnet and the formation of plagioclase, as both discrete grains and as an intergrowth with amphibole or spinel around relict garnet kernals (Plate 5.2d). At the same time olivine was replaced by amphibole and primary pyroxene became sieved with plagioclase and mantled by amphibole.

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### 5.3 MINERAL CHEMISTRY

This section summarises the chemical variation within mineral assemblages from the various lithologies. Details of microprobe techniques together with calculated means and standard deviations for the analyses are given in Appendix III. The mineralogy and recalculation schemes are summarised in Appendix I, Table AI.1 and Appendix IV respectively.

### 5.3.1 GRANULITES AND UNDIFFERENTIATED AMPHIBOLITE FACIES GNEISSES

#### Plagioclase

Plagioclase composition varies between subdomains and lithologies (Table 5.1). In Opeongo subdomain, mafic granulites tend to contain more calcic plagioclase  $(An_{45-59})$  than leucocratic rock types  $(An_{30-34})$ . Elsewhere, both mafic and intermediate granulites contain plagioclase from  $An_{29-42}$ , although a granulite with rare orthopyroxene from the margin of Rosseau subdomain contains  $An_{18-19}$ . Plagioclase typically exhibits reverse zoning with more calcic rims ("rev" in Table 5.2) but by no more than a few mol% anorthite. In amphibolite facies gneisses, plagioclase has only been analysed from Go Home subdomain where it ranges from  $An_{26}$  in a quartzo-feldspathic orthogneiss, to  $An_{25-37}$  in intermediate bulk compositions.

#### Pyroxene

Coexisting ortho- and clinopyroxenes are common in the intermediate and mafic granulites. Ferric iron has been estimated using the charge balance method of Ryburn et al. (1976) and the resulting site occupancies are plotted in Figure 5.2. The average tetrahedral(VI) vs. octahedral(IV) Al sites for coexsting pyroxene pairs, define an inverse correlation (Fig. 5.2a). A similar relationship exists for recalculated Fe3 vs. Al(VI), although a poor correlation results when Al(VI) is plotted against Na and in many samples, Al(VI) appears to be independent of the Na content. This contrasts the metagabbros where a strong positive correlation exists (Chapter 6, section 6.4). However the recalculated end member phase components show variations in Jadeite (from 3-9 mol%) and Ca-Tschermaks (0-7 mol%), implying coupled substitution of Al as both Jd and Ts molecules. The recalculated quadrilateral components (following Lindsley, 1983) are plotted in Figure 5.7a. Mean compositions for coexisting Opx±Cpx ±Gt pairs are plotted in the Ca-Fe-Mg triangle in Figure 5.3a and show a

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			CADUET.	P. 7
JAMPLE NO.	PLAG	PTX	GAHNE 1	P-I assemblage
84DMS-111	An32-34	-	slight MnMg-1 (R)	Gt-hbl-biot
84DMS-124	An35-37	-	(MnCa)Mg-1 (R)	Gt-biot
84DMS-173	An26	-	MnMg-1 (R)	Gt-biot
GRANULITES				
85DMS-2A	An31-37(rev)	n/z	FeCa-1 (R)	Gt-opx-cpx-pl-qtz
B4DMSA-1A	An50-54	n/z	-	Орх-срх
84DMSA-5A	An30-32	n/z	n/z	Gt-cpx-pl-qtz
B4DMSA-44	An55-59	n/z	FeCa-1 (R)	Gt-opx-cpx-pl-qtz
84DMSA-94B	An44-48	n/z	FeCa-1 (R)	Gt-cpx-pl
85DMSA-166	An31-34	n/z	n/z	Gt-opx-pl-qtz-bi
850MSH-100	An33-40(rev)	n/z	FeCa-1	Gt-opx-cpx-pl-qtz
B5DMSH-108A	An29-31	n/z	n/z	Gt-opx-cpx-pl
850MSR-27	An18-19	n/z	n/z	Gt-cpx-pl-qtz-hbl
B5DMSP-5A	An38-39	n/z	minor FeMg-1 (R)	Gt-opx-pl-qtz-bi
850MSP-16	An33-35	n/z	-	Орх-срх
PELITIC AND	SEMI-PELITIC G	NEISS	<u> </u>	
 84DMS-68	An20-23		MnFe(Ma)-1 (R)	Gt-sill-pl-qtz-bi
B4DMSA-160	An26-29	-	n/z	Gt-sill-pl-qtz
85DMSH-110	An31-37(rev)	n/z	n/z	Gt-cpx-pl-qtz-bi-hbl
B5DMSH-111A	An28-30	_	minor FeMg-1 (R)	Gt-sill-pl-qtz-bi
850MS0-76	An39-4	n/z	n/z	Gt-opx-pl-qtz-bi
85DMSD-138A	An40-41	n/z	n/z: rare MgCa-1 (R)	Gt-opx-pl-qtz-bi
85DMSP-7	An24-28(rev)	-	FeMa-1 (R)	Gt-sill-pl-qtz-bi
85DMSP-13A	An29-31	-	(FeMn)Mg-1 (R)	Gt-ky-pl-qtz-bi-musc
ANORTHOSITIC	GNEISS			
 84DMS-27C	An60-78		FeCa-1 (R)	Gt-hbl
84DMS-35C	An52-64	-	_	Pl-hbl
84DMS-57D	An70-76	-	FeMg-1 (R)	Gt-hbl
84DMS-134A	An59-68	_	n/z	Gt-hbl
840MS-134C	An54-67	-	n/z	Gt-hbl
85DMS-51R	An61-81	n/z	Fe(MoCa)-1 (R)	Gt-cpx-pl-hbl
850MSR-6	An31-41(rav)	n/z	Ma(Ca+Fe)=1 (R)	Gt-cpx-pl-hbl
85DMS8-16A		n/7	minor CaFe-1 (R)	Gt-cpx-pl
85DMSP-3C	An48-52	n/z	Ca(Mg+Fe)-1 (R)	Gt-cpx-pl
ULTRAMAFIC A	ND AMPHIBOLITE	S		
840MS-51F	An25-29	n/z	Fe(MgCa)-1 (R)	UT-CPX-PI
840MS-172B	An31-40(rev)	-	n/z	
850MSH-78	-	n/z	-	upx-cpx
USDMSH-107A	An72-80	n/z	-	Upx-cpx
115 CHACKI 4636	An50-55(rev)	n/z	n/z	ut-opx-cpx-pi-qtz
BOUNSH-107C			E M. 4 (D)	にまっへのソックのソッチの
85DMSH-107C	-	n/z	Feng-1 (H)	BC-opy-cpy op
850MSH-107C 850MSH-102C 850MSR-15	-	n/z n/z	n/z	Gt-opx-cpx-sp

# 

FIGURE 5.2: Recalculated site occupancies for pyroxenes from granulites. Tielines in Fig. 5.2a join coexisting means for opx and cpx.


regular distribution with rare crossing tie-lines which implies consistent phase equilibria during continuous reactions, for a variety of lithologies.

#### Garnet

The grossular content in granulites varies from 5-10% in 85DMSA-166 to 24% in 85DMSH-100. The pyrope content does not exceed 30 mol% while the recalculated andradite content ranges from 0-8% and the Ca content for most compositions can be represented by  $Gr_{15-30}And_{2-8}$  (Fig. 5.3b). Some samples show negligible zoning and the overall core to rim variation is commonly less than the variation within a polished section. In others, the rim compositions are variably depleted in Ca by FeCa<sub>-1</sub> exchange (Table 5.2), although 85DMSP-5A is an exception to this because the rims are still Fe-rich but in this case, by FeMg<sub>-1</sub> exchange.

In the amphibolite facies gneisses from Go Home subdomain, garnets are normally richer in Mn (by up to 6 Wt%) and zoning involves  $MnMg_{-1}$ exchange from core to rim. Grossular contents range from 16-30 and Andradite from 0-10 mol%.

## Amphiboles

The recalculated amphibole compositions (Papike et al., 1974) range from edenitic to pargasitic hornblendes (Leake, 1978). The recalculated site occupancies are plotted in Figure 5.4 where sample 85DMSR-27 plots off the main trends, being depleted in octahedral Al(VI) and much more Ferich (Fig. 5.4c). Disregarding this, amphiboles from amphibolite facies gneisses are lower in Ti (Fig. 5.4c) and richer in Fe and there is a gradual depletion in the edenite component from amphibolites to granulites (Fig. 5.4e & f). In addition, amphibolites define a slope of  $\infty$  -0.5 in Na(M4) vs. Total Ca (Fig. 5.4d) whereas granulites define higher negative slopes up to  $\infty$  -1.0 which suggests greater amounts of coupled exchange, involving (Na+Fe)<sub>N4</sub> in the amphibolite facies gneisses. The A-site occupancies (Na+K)<sub>A</sub> are plotted against tetrahedral Al(IV) in Fig. 5.4e where individual samples define poor trends, but the overall variation is compatible with increasing amounts of the pargasite molecule.

# Biotites

Biotite analyses have not been recalculated to give Fe<sup>3+</sup> and the site occupancies determined directly from microprobe analyses are plotted for all lithologies in Figure 5.5. In the "ideal biotite plane" (Figure 5.5a;

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FIGURE 5.3b: Recalculated garnet end-member compositions in granulites.





FIGURE 5.4: Recalculated site occupancies for amphiboles from a variety of lithologies in the CGB.

Guidotti, 1982) the biotites from amphibolite and granulite facies gneisses lie at intermediate compositions, close to the annite-phlogopite join. Any composition in this figure can be modelled by a combination of Tschermaks  $(Al^{VI}Al^{IV}Si_{-1}Mg_{-1})$  and FeMg\_1 exchange from the phlogopite end-member. The main deviation from this plane is caused by Ti substituting into octahedral sites (Fig. 5.5b to d) which is correlated with a decrease in Al(VI) and increasing vacancies in the octahedral sites (Fig. 5.5b,c) by:

 $2(R^{2+})^{v_i} = (Ti^{4+})^{v_i} + ()^{v_i}$  and  $2(A1^{3+})^{v_i} = (Ti^{4+})^{v_i} + R^{2+}$ 

# 5.3.2. METASEDIMENTS

## Pelites & semi-pelites

The plagioclase composition varies from  $An_{20-31}$  in pelites and from  $An_{31-41}$  in semi-pelitic and aluminosilicate-free samples (e.g. 85DMSD-76, 85DMSD-138A and 85DMSH-110A), any zoning being reversed. Garnet compositions vary in terms of the grossular content; in pelites it ranges from 0-8 mol% with up to 60 mol% pyrope (in 85DMSP-7), whereas in semi-pelites grossular constitutes 16-26 mol%. In both pelites and semi-pelites and radite ranges from 0-6 mol% and spessartine 0-3mol%. Zoning if present, involves minor Fe-enriched rims by FeMg\_1 exchange. The biotites with the exception of 85DMSH-111, are magnesian and plot in the field of phlogopites (PARA, Fig. 5.5a).

## Marbles & calc-silicates

Plagioclase (An25-29) is present in the marbles and calc-silicates from Go Home subdomain. Mafic minerals are not significantly zoned and clinopyroxene is almost wholly represented by the diopside-hedenbergite solid solution with minor ( $\sim$  4 mol7 Jd). Garnet is almost pure grossular with 10-15% and radite and < 5% (Alm+Pyr). The sample of skarn from Opeongo (84DMSA-17B) contains pyroxene with  $\sim$  80% hedenbergite and recalculated site occupancies show significantly higher ferric iron. Here the composition of garnet varies from core to rim by FeCa<sub>-1</sub> exchange and the recalculated Fe<sup>3+</sup> is highly variable, resulting in and radite contents of between 10 and 40% (Fig. 5.6a).



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## 5.3.3. ANORTHOSITIC GNEISS

In this section the mineral chemistry of anorthositic gneiss is compared with two relict garnet-clinopyroxene (meta-eclogitic?) pods (85DMSR-6 and 84DMS-518). The latter are superficially similar to each other, but DMSR-6 is wholly enclosed by the anorthosite whereas, DMS-518 is enclosed within highly strained gneiss adjacent to anorthosite. The latter also contains more amphibole and plagioclase than DMSR-6 and very little relict pyroxene (Plate 5.2a). They both may be unrelated to the anorthosite but are included here for comparison.

## Plagioclase

Plagioclase varies in composition from  $An_{60-76}$  in mafic gneiss derived from leucogabbro, to  $An_{48-64}$  in "true" anorthosite. Each of the "meta-eclogitic" pods have distinctly different compositions: in R-6 it is relatively sodic  $(An_{31-41})$ , whereas in DMS-51B it ranges from  $An_{58-80}$ where calcic compositions occur in the plagioclase moats immediately adjacent to garnet.

## Pyroxene

Relict igneous pyroxenes are retained in both samples of leucogabbro 85DMSR-16A and 85DMSP-3C and in the mafic pods. They are not significantly zoned and all contain between 5 and 10% of the Jd molecule with a good positive correlation between Na and Al(VI) site occupancies.

## Garnet

The recalculated end-member compositions are given in Figure 5.5b where the normalised grossular component ranges from 5-30 molf and it exchanges for both pyrope and almandine. In anorthosites compositional zoning from core to rim involves  $FeCa_{-1}$  or  $FeMg_{-1}$  (84DMS-27C) exchange, while leucogabbros possess Ca-rich rims by CaFe-1 (R-16A) and Ca[Mg±Fe]\_1 (P-3C) exchange. The zoning patterns are ambiguous in mafic lenses; rim compositions in DMSR-6 are magnesian by Mg[Ca±Fe]\_1 exchange, whereas quite the opposite is observed in DMS-51B, where rims are iron-rich.

#### Amphiboles

The recalculated amphibole compositions are represented in Figure 5.4 and with the exception of the low-alumina amphiboles in 84DMS-134A, are all pargasitic hornblendes; in 84DMS-134A, pale actinolite-anthophyllite has replaced the orthopyroxene core and is surrounded by green pargasitic

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hornblende. The compositional variation within samples is represented by increasing amounts of the pargasite molecule, coupled with minor Tschermaks (TS) exchange (Fig. 5.4). When total Ca is plotted against Na(M4) a strong inverse correlation exists with a gradient of  $\sim$  -0.5 (Fig. 5.4) and corresponds to lower amounts of [Ca + Na(M4)] in Ca-poor samples; i.e. coupled substitution for Ca.

# 5.3.4 AMPHIBOLITES, ULTRAMAFICS & PERIDOTITES

#### Amphibolites

In amphibolite layers and lenses within the host gneisses plagioclase ranges in composition from  $(An_{25-40})$ . This is considerably less calcic than the plagioclase moat composition in 84DMS-518  $(An_{61-81})$  and the plagioclase in a relict metagabbro (85DMSH-107C,  $An_{50-55}$ ); the latter is unrelated geochemically to the coronite metagabbros (Chapters 4, 6) and appears to represent a different gabbroic suite associated with units of pyroxenite (85DMSH-107A). Some amphibolites contain clinopyroxene which is typically replaced by pargasitic hornblende. The amphiboles are considerably more Fe-rich and Al(VI)-poor than amphibole in ultramafic compositions and like the anorthosites, plot with a slope of -0.5 when Na(M4) is plotted against total Ca.

# Peridotites

Three 'peridotites' containing olivine (Fo, ) have been analysed (85DMSH-102C, 85DMSR-15 & 85DMSD-10B). Pyroxene exhibits negligible zoning and with the exception of DMSR-15, contains 5-10% Jd; in R-15 jadeite constitutes up to 30% (7 Wt%  $Al_2 O_3$ ). This probably represents relict high alumina pyroxene before the exsolution of spinel. Garnets contain 10-15 mol% grossular and up to 60% pyrope (Fig. 5.6c). Amphiboles plot towards pargasite (Fig. 5.4e) and biotites are phlogopitic with a Mg No. of 80-83 (Fig. 5.5a). The green spinel which forms a symplectite with pyroxene has a Mg No. of 51-60 and variable Cr (0.4 Wt% in DMSH-102C to 1.7-4.2 Wt% in DMSD-10B). There are also discrete grains of opaque Cr-spinel which contains 20-33 Wt7 Cr<sub>2</sub>O<sub>3</sub> in R-15 and 38-54 Wt7 in D-10B. Chrome constitutes less than 0.1 Wt% in olivine, pyroxene and garnet, and less than 0.2 Wt% in amphibole and phlogopite in all samples except R-15; here relict clinopyroxene contains around 1.0 Wt% chrome. This, together with the high alumina content, suggests R-15 is the least-evolved peridotite in terms of continuous and discontinuous decompression reactions because the

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exsolution of spinel(+Cr) from pyroxene has not progressed to the same extent as in H-102C. Neither contains plagioclase, although other samples at locality H-102 do and are texturally analogous to DMSD-10B. Plagioclase formed by breakdown of pyroxene and garnet (Plate 5.2d) and ranges in composition from  $An_{60-87}$ . This represents a disequilibrium compositional variation because plagioclase is considerably more calcic immediately adjacent to spinel and garnet.

# 5.4 PHYSICAL CONDITIONS OF METAMORPHISM: P.T & FLUID COMPOSITION

## 5.4.1 INTRODUCTION

There have been several recent reviews on various aspects of geothermobarometry, including Essene (1982), Bohlen et al. (1983b) and Powell (1985) which highlighted many applicational problems, some of which are summarised below.

(i) The importance of identifying true equililbrium assemblages.

- (ii) The problem of subsequent re-equilibration by intergranular diffusion during cooling which resets cation distributions and/or hampers identification of the original equilibrium assemblage. In addition, individual minerals re-equilibrate to different closure temperatures (equivalent to the blocking temperature in isotope studies); Bohlen et al. (1985) suggest 575-600°C as a probable blocking temperature in garnets, while Davidson & Lindsley (1985) propose 500-550°C as the lower limit for intercrystalline exchange within pyroxenes.
- (iii) The fluid composition is normally unknown and may have varied at the time of metamorphism.
- (iv) An incomplete thermodynamic data base. All methods of calculating pressure and temperature require a rearrangement of the simple equilibrium relation  $\Delta G^{\circ}$  + RTlnK = 0 for balanced chemical reactions, where the various thermometers and barometers rely on the T or P dependence of the equilibrium constant K, which should be independent of bulk composition. However the application of this relation to natural samples is fraught with problems for the following reasons:
  - Inaccuracies in the existing thermodynamic data magnify errors when for example, two large numbers are subtracted. In recent years the development of internally consistent data sets has begun to put

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tighter constraints on this problem.

- The mixing properties for many phases are poorly known (Chapter 6, section 6.9).
- The available data refer to minerals in a specific structural state. This together with the extent of disorder, is not normally known at the time of metamorphism.
- Experiments to locate the end-member reactions are usually carried out at significantly different conditions to those prevailing during metamorphism which leads to problems in extrapolation.
- (v) Uncertainties introduced from microprobe analyses especially when an element is present in only small quantites. Further problems are introduced by the recalculation of ferric iron and in the choice of site occupancies. The following P-T results incorporate charge balance determinations of  $Fe^{3+}$ . This has a non-negligible effect on the gt-cpx thermometer and the difference is given in brackets in Table 5.3a.

The equilibrium assemblages amenable to geothermobarometry in this part of the CGB are summarised in Table 5.2. In each case the core composition of coexisting phases is assumed to represent equilibrium partitioning at the time of metamorphism. A variety of independent geothermometers and geobarometers have been applied and a summary of each is presented below; readers are referred to the cited papers for a fuller discussion. However, before presenting results it is useful to consider petrogenetic grid in Figure 5.1 (modified after constraints from the Essene, 1982). This delimits a P-T region for the CGB with the exception of the PSSZ, beyond muscovite breakdown and within the sillimanite stability field. Although many petrogenetic grids are available for marbles and calc-silicates there are not enough occurrences to warrant their application here because the P-T location of many reactions is strongly dependant on the fluid composition. However the reaction Qtz + Gr + An + Wo has been located in the CaO-A1 $_2O_3$ -SiO $_2$ -H $_2O$  system by Perkins et al. (1980) and represents a maximum upper limit for reactions in the natural example where additional components are introduced. This reaction does not involve  $CO_2$  and hence is independent of the fluid composition. Thus grossular rims between An and wollastonite in 85DMSH-103A represent a useful down-temperature back-reaction and delimits a minimum temperature for peak metamorphism.

# 5.4.2 TEMPERATURE ESTIMATES

Five independent thermometers have been applied: the garnetclinopyroxene (Ellis & Green, 1979); garnet-orthopyroxene (Harley, 1984a; Sen & Bhattacharya, 1984); garnet-biotite (Ferry & Spear, 1978; Hodges & Spear, 1982; Indares & Martignole, 1985); garnet-hornblende (Wells, 1979; Graham & Powell, 1984) and orthopyroxene-clinopyroxene (Lindsley & Anderson, 1983; Lindsley, 1983). The results are presented in Table 5.3a and Figure 5.7.

# Garnet-clinopyroxene

This thermometer is based on preferential partitioning of Mg into garnet rather than clinopyroxene as the temperature increases. The thermometer has been calibrated by many workers although not one of the available calibrations incorporates mixing models for cpx that accommodate significant Jadeite solid solution (> 10 mol%) and the associated cation al. (1983) evaluated the various available ordering. Johnson et formulations and found Ellis & Green (1979) to be most consistent and results from this method [E & G] are presented in Table 5.3a. However they suggest the activity models do not accomodate large variations in bulk composition and further that they underestimate temperature when garnet contains >10 molf spessartine. The latter is never observed in the CGB examples but several samples do contain > 10 mol7 Jd (e.g. 85DMSR-15 and also results in large and variable ferric iron 85DMSK-10) which determinations; in 85DMSR-15 and 85DMSH-102C this decreases the estimated temperature by around 100°C. In spite of these problems the [E & G] thermometer does produce relatively consistent results of 675-750+50°C although in some cases, rare high-Ca garnet cores give anomalous temperature estimates of 840-900°C; these samples are denoted by a (\*) in Table 5.3a.

## Garnet-orthopyroxene

This thermometer is based on the Fe-Mg distribution between coexisting garnet-opx pairs and is applicable in granulites and garnet peridotites. It has been calibrated by Harley (1984a) [HAR] and Sen & Bhattacharya (1984) [S & B]. In the CGB, garnet and opx are not always in equilibrium but it has been applied to several two pyroxene-garnet granulites where results can be compared with the gt-cpx thermometer (Table 5.3a). This suggests that the [S & B] formulation tends to overestimate temperatures relative to [E & G], whereas [HAR] underestimates or

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TABLE 5-38: Temperature estimates (the temperature in brackets corresponds to the difference (+/-) with no ferric iron). Abbreviations: Gran -granulite; Gn -undivided gneiss; Pel -pelitic & semi-pelitic gneiss; Anor -anorthositic gneiss; Per -peridotite; Maf -amphibolite/pyroxenite.

#### SUBDOMAIN

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#### GEOTHERMOMETER

60 HOME	GT-CPX(E & G)	GT-OPX(HAR)	[S & B]	GT-BI(H & S)	[F & S]	GT-HOLLG &	PI (WELLS)
850MS-2A (Gran)	690-740°C (+0-20°C)	650-670°C	750-780°C				********
840HS-111 (Gn)	•	-		700-735°C	625-640(Gr15)	650-675°C	660-680
840MS-124 (Gn)	-	• •		700-750°C	620-660(Gr20)	660-690°C	650-680
840MS-173 (Gn)	-	-		675-710°C	600-650(Gr14)	-	
840MS-68 (Pel)		-		845-880°C	820-850(Gr2;*81	.) -	
840MS-27C (Anor)-	-	- '			-	650-675 <sup>°</sup> C	700-725
840HS-570 (Anor)	-	-		-	-	640-670°C	710-750
84DMS-134A (Anor)	•	-		-	-	555-590°C	655-690
840MS-134C (Anor)	-	-	-	-	-	640-675°C	690-725
840MS-518 (Maf)	*770-825°C(+20-60°C)	-		-	-	775-860°C	740-780
840MS-1728 (Maf)	-	<b>-</b>		-	-	650-725°C	660-710
OPEONGO	GT-CPX(E & G)	GT-OPX[HAR]	[S & B]	GT-BICH & SI	(F & S)	GT-HBLIG &	P][WELLS]
84DMSA-5A (Gran)	700-725°C(+10-30°C)	*			-	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	
840MSA-44 (Gran)	*700-735°C(+20-60°C)	690-730°C	800-850°C	-	-	-	
840MSA-948 (Gran)	*700-730°C(+10-50°C)	-	-	-	-		
850MSA-166 (Gran)	-	640-660°C	720-750°C	710-740°C	670-700°C(Gr7)	) -	
HUNTSVILLE	GT-CPX[E & G]	GT-OPX(HAR)	[S & B]	GT-BI(H & S)	(F & S)	GT-HBLIG &	P][WELLS]
850MSH-100 (Gran)	710-770 (+50-60°C)	650-720°C	 750-825°C		-	-	
850MSH-108A (Gran)	670-710 (+20-30°C)	620-670°C	730-770°C	-	-	-	
850MSH-110 (Pel)	675-725 (+20-30°C)	-		750-800°C	675-690(Gr20)	-	
850MSH-111 (P+1)	•	-		620-660°C	605-640(Gr3)	-	
850MSH-102C (Per)	600-700 (+100°C)	700-800°C	800-950°C	-	-	-	
850MSH-107C (Maf)	725-745 (+40-60°C)	720-760°C	850-910°C	-	-	-	
ROSSEAU	GT-CPX(E & G)	GT-OPX[HAR]	[8 4 2]	GT-BICH & SI	(F & S)	GT-HBLEG &	P] [WELLS]
850MSR-27 (Gran)	680-700 (min. Fe3)			-	-		
850MSR-16A (Anor)	675-700 (+10-30°C)	-	-	-	-		
85DMSR-6 (Maf)	675-750 (+10-30°C)	-	-	-	-		
85DMSR-15 (Per)	720-780 (+70-100 <sup>°</sup> C)	680-760°C	770-900°C	-	-	-	
PSSZ	GT-CPX(E & G)	GT-OPX(HAR)	[5 & 9]	GT-BI(H & S)	(F & S)	GT-HBLIG &	P][WELLS]
850MSP-13A (Pel)	***************************************		695-725°C	665-690°C(Gr	5) -		
850MSP-3C (Anor)	725-775 (+ 50 <sup>°</sup> C)	-	-	-	-		
PARRY SOUND	GT-CPX(E & G)	GT-OPX(HAR)	[5 & 8]	GT-BICH & SJ	(F & S)	GT-HBLIG &	PI[WELLS]
ASDMSD_EA (Care)	***************************************			845-900 0	785-820(Gr14)	-	
850MSP-7 (Pel)	- 6	-	) (30-850	640-770°C	650-760(Gr1)		
KAWAGAMA & MCLINTO	CK GT-CPX(E & G]	GT-OPX(HAR)	[S & B]	GT-BI(H & S)	(F & S)	GT-HBLIG	P) (WELLS)
850MS0-76 (Pall	*******	595_625 <sup>0</sup> C	600_715 <sup>0</sup> C	750-800°C	655-710°C(Gr18	3) -	
850NS0-10 1FELI	-	555_690 <sup>0</sup> C	600-710 C	715-750 0	620-640°C(Gr16	3) -	
950H20-100 /			740-770 <sup>0</sup> 0			-	
esunsu-ius (per)	290-1901290-120 Cl	ojumodu L	1404110 G	-			

overlaps it.

#### Garnet-biotite

The Fe-Mg exchange between garnet and biotite has been calibrated by many workers, although Bohlen & Essene (1980) proposed that it does not work well in amphibolite to granulite grade rocks because of increasing amounts of Ti, F, Cl and possibly ferric iron in biotite at higher temperatures, coupled with problems of re-equilibration during cooling. Nonetheless it has been applied here where the Ferry & Spear (1978) [F & S] and Hodges & Spear (1982) [H & S] formulations produce the most consistent results. The [F & S] calibration assumes ideal mixing in garnet and should not be applied when  $X_{r_a}^{6t}$  exceeds 0.2 or when biotite has Al(VI)+Ti/(Al(VI)+Ti+Fe<sup>2</sup>+Mg) greater than 0.15 (denoted by \*Bi in Table 5.3a). It was modified to take into account non-ideal garnet solid solution by Hodges & Spear (1982) using the mixing model of Ganguly & Kennedy (1974) which attempts to correct for Ca in garnet, resulting in higher temperatures than the [F & S] calibration; the discrepancy narrowing with decreasing grossular. A further modification was proposed by Indares & Martignole (1985) [I & M] to accommodate excess Al and Ti in biotite and non-ideal mixing in garnet. In 84DMS-6 and 85DMSP-5A this produced temperatures of 620-700°C in accord with other thermometers and below the erroneously high [F & S] and [H & S] results. In general however the [I & M] formulation produces both scattered and low estimates of temperature.

## Garnet-hornblende

This is based on Fe-Mg exchange between garnet and hornblende and there are two formulations available: Graham & Powell (1984) [G & P] and Wells (1979) [WELLS]. It is applicable in amphibolite to granulite grade rocks where the temperature did not exceed  $850^{\circ}$ C. It has been applied to the amphibolites in the CGB and the results are presented in Table 5.3a. Below  $700^{\circ}$ C, the [G & P] thermometer results in lower temperature estimates than the [WELLS] formulation, whereas above this temperature the two overlap or the converse occurs.

## Orthopyroxene-clinopyroxene

Many two pyroxene solvus thermometers have been formulated but Lindsley (1983) proposes that only Kretz (1982), Lindsley & Anderson (1983) and Ross & Huebner (1975) are successful for a wide range of Compositions. However, not one makes adequate corrections for non-

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FIGURE 5.7: Graphical two-pyroxene thermometer applied to granulite facies assemblages (a) and peridotites/pyroxenites (b).







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quadrilateral components and they should only be applied if Wo+En+Fs exceeds 90 molf, although recent work by Gasparik (1987) implies that the Ca distribution of quadrilateral components can be extended without modification, to aluminous compositions. In this study the graphical thermometer of Lindsley & Anderson (1983) and Lindsley (1983) has been applied. It is based on decreasing Ca in augite and increasing Ca in orthopyroxene as the temperature increases. The estimated uncertainty is [±50°C + 5x(molf non-quad. comp.)] (Lindsley & Anderson, 1983), which results in unreliable results for 85DMSR-15. It was evaluated by Docka et al. (1986) who suggested that it is useful for rocks that equilibrated between 750-950°C, but may be inadequate for lower temperature pyroxenes. Coexisting pyroxenes in the CGB probably lie just within this range and the results presented in Figure 5.7a, suggest temperatures around 700-750°C for granulites and 800-1000°C for the garnet peridotite samples 85DMSH-102C and 85DMSD-10B, where non-quadrilateral components are lower than in 85DMSR-15 (Fig. 5.7b). In every case orthopyroxene plots at lower temperatures around 600°C, consistent with re-equilibration during cooling.

## 5.4.3 PRESSURE ESTIMATES

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Most geobarometers are based on reactions involving garnet because of the large volume changes involved. The barometers applicable in the CGB include: garnet-orthopyroxene-plagioclase-quartz (Newton & Perkins, 1982; Bohlen et al., 1983b; Perkins & Chipera, 1985); garnet-clinopyroxeneplagioclase-quartz (Newton & Perkins, 1982); garnet-aluminosilicateplagioclase-quartz (Newton & Haselton, 1981); garnet-orthopyroxene (Harley & Green, 1982; Harley, 1984b) and garnet-olivine-plagioclase (Bohlen et al., 1983b). In all cases the charge balance estimates of ferric iron have been accommodated but this makes very little difference to the calculated pressures (< 0.2 Kbars) which is well within the uncertainty attached to each calibration (Table 5.3b).

## Garnet-orthopyroxene-plagioclase-quartz

This barometer was calibrated for the two end-member reactions: Gross + 2Pyr +  $3Qtz \rightarrow .3En + 3An$  [Mg, CMAS]; (Newton & Perkins, 1982; Perkins & Chipera, 1985) and Gross +  $2Alm + 3Qtz \rightarrow 3Fs + 3An$  [Fe, FCAS]; (Bohlen et al., 1983b; Perkins & Chipera, 1985), although Perkins & Chipera (1985) [P & C] proposed that the [Fe] calibration of Bohlen et al.

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(1983b) is incorrect. Again the lack of well determined activity data for garnet and pyroxene is a major source of uncertainty in the application of this barometer from either the CFAS or CMAS systems. Perkins & Chipera (1985) adopted the recent Ganguly & Saxena mixing model for garnet and the results from both the [Fe] and [Mg] calibrations are presented in Table 5.3b where the estimated uncertainty is +1 Kbar (Perkins & Chipera, 1985). Ideally both formulations should give identical pressure estimates, but this is not the case and the [Fe] reaction typically gives lower pressures. This was also noted by Perkins & Chipera (1985) who suggested that the [Fe] calibration should be used in more iron-rich systems. because the mixing model for extrapolation from CMAS into FCMAS is inaccurate at these compositions. In the CGB most garnets and pyroxenes have intermediate compositions and the best estimate of pressure probably between the [Fe] and [Mg] results, but biased towards the [Fe] lies reaction. Furthermore, several mafic granulites contain no free quartz and here the estimated pressure represents a maximum (i.e. at reduced silica activity). The results in Table 5.3b range from 8-10 Kbars and represent an increase of 1-2 Kbars when compared with the original calibration of the [Mg] reaction by Newton & Perkins (1982).

## Garnet-clinopyroxene-plagioclase-quartz

This was formulated by Newton & Perkins (1982) and was applied to samples from the CGB using the original recommended garnet mixing model from Ganguly & Kennedy (1974). The results are presented for comparison in Table 5.3b and are less consistent and at least 2-3 Kbars lower than the equivalent [Mg] estimates from Perkins & Chipera (1985), although the calculated pressures increase by  $\sim 1-2$  Kb if the Ganguly & Saxena (1985) garnet model is applied.

## Garnet-aluminosilicate-plagioclase-quartz

This barometer is based on the reaction  $3An \rightarrow Gross + 2Alsil + Qtz$ and was formulated by Newton & Haselton (1981), but was applied using the corrected sillimanite reaction from Ganguly & Saxena (1984). This barometer is not ideal because it has a strong temperature dependency and was calibrated at high pressures, thus requiring large extrapolations back to granulite facies conditions. Moreover it has been applied to pelitic rocks where grossular contents in garnet are low, providing further uncertainties from the poorly known mixing properties of garnet. Results are given in Table 5.3b and a reasonable overlap exists with the lower range obtained from gt-opx-pl-qtz [Fe] barometry, although 85DMSP-7

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TABLE 5.3b: Pressure estimates (abbreviations as before).

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# GEOBAROMETER

GQ HOME	GT-OPX-PL-QTZ [P & C; Mg]	[Fø]	XFe	GT-ALSIL-PL-QTZ (N & H)	GT-CPX-P1-QTZ IN & PI
85DMS-2A (Gran) 84DMS-68 (Pel) 84DMS-518 (Maf)	9.8-11 Kbars 2 700-750°C - -	8-9.7 - -	.5354	- 7.5-8.8 Kbars @ 700°C -	(7)8.4-9.5Kbars - 7.5-8.5 Kbars
OPEONGO	GT-OPX-PL-QTZ (P & C; Mg)	[Fe]	XFe	GT-ALSIL-PL-QTZ (N & H)	GT-CPX-PL-QTZ (N & P)
840MSA-5A (Gran) 840MSA-44 (Gran) 840MSA-948 (GRAN) 850MSA-166 (Gran)	9.3-10.3 Kb a 700-725°C - 7.7-8.2 Kb a 750°C	7.8-8.4 as [Mg]	.4649	- · - -	5.2-6.2 Kbare 7.2-7.7 Kbare 5.2-6.1 Kbare
84DMSA-160 (Pel)	-	-	•	7.0-7.6 Kbars	-
HINTSVILLE	GT-OPX-PL-QTZ (P & C; Mg)	[Fe]	XF•	GT-ALSIL-PL-QTZ (N & H)	GT-CPX-P1-QTZ (N & P)
85DMSH-100 (Gran) 85DMSH-108A (Gran) 85DMSH-110 (Pel) 85DMSH-111A (Pel) 85DMSH-107C (Maf)	9.5-10.5 Kb a 710-770°C 10-10.4 Kb (max., no qtz) - - 9.0-9.5 Kb a 725-775°C	as [Mg] 7.9-8.8 - - 8.2-8.9	.4041 .5859 .4445	- - 6.2-8.2 a 700-750°C -	6.8-7.9 Kbars 5.4-6.0 (max., no qtz) 7.3-8.1 Kbars
ROSSEAU	GT-OPX-PL-QTZ (P & C; Mg)	[Fe]	XFe	GT-ALSIL-PL-QTZ (N & H)	GT-CPX-P1-QTZ (N & P1
85DMSR-27 (Gran) 85DMSR-6 (Maf)		-			6.2-6.4 Kbars
PSSZ	GT-OPX-PL-QTZ [P & C; Mg]	[Fe]	XFe	GT-ALSIL-PL-QTZ (N & H)	GT-CPX-P1-QTZ (N & P)
85DMSP-13A (Pel) 85DMSP-3C (Anor)	-			6.7-8.5(9.8)Kb @ 665-725 -	°C - 6.1-6.8 Kbare
PARRY SOUND	GT-OPX-PL-QTZ (P & C; Mg)	[Fe]	XFe	GT-ALSIL-PL-QTZ (N & H)	GT-CPX-P1-QTZ (N & P)
85DMSP-5A (Gran) 85DMSP-7 (Pel)	9.5-10.1Kb a 700-725°C -	8.6-9.5	.4445	_ 5.0-6.6 Kbars	-
KANAGAMA & MCLINTO	CK GT-OPX-PL-QTZ [P & C; Mg	] [Fe]	XFe	GT-ALSIL-PL-QTZ (N & H)	
85DMSD-76 (Pel) 85DMSD-138A (Pel)	8.6-9.5 кь а 700-750°C 8.2-8.9 кь а 700°C	7.6-8.9 7.2-7.8	.5355		

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produces significantly lower but consistent results and may have re-equilibrated on cooling.

# Garnet-orthopyroxene

The formulations of Harley & Green (1982) and Harley (1984b) have been applied to suitable samples from the CGB but give erroneously high and scattered estimates of pressure. These are not presented in Table 5.3b.

## Garnet-olivine-plagiocase

This barometer is based on the reaction  $3Fa + 3An \rightarrow Gross + 2Alm$  in the FCAS system (Bohlen et al., 1983b) using the garnet mixing model of Perkins (1979). It is not applicable to the relict garnet peridotite (85DMSD-108) because plagioclase was not in equilibrium with olivine and garnet. However it is useful in the coronite metagabbros and this is discussed in Chapter 6, section 6.8 where results are presented in Table 5.8.

# 5.4.4 SUMMARY OF P-T RESULTS

The following table summarises P-T estimates from application of the above geothermometers and barometers and compares them with estimates of Anovitz & Essene (1985) and Anovitz (pers. comm.). The values represent weighted results where the means from gt-cpx, opx-cpx and transitional gt-opx temperatures are considered to be most reliable, together with the pressure estimates from gt-opx-plag-qtz barometry, biased towards the [Fe] reaction.

# Table 5.4

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SUBDOMAIN	TEMP (°C)	PRESSURE(Kbars)	Anovitz(pers. comm.)
Go Home	710-720	8.2-9.7	680-760, 9.5-10.5Kb
Opeongo	710-720	7.3-8.4	710-770, 9-10.0Kb
Huntsville	700-740	8.5-10.5	730-830, 9.3-10.6Kb
Rosseau	690-710	6.27(+ 1-3Kb)	670-780, 8.9-10.5Kb
PSSZ	690-750	6.7-8.5	680-<730, <8.1-9.8Kb
Parry Sound	700-740	9.0-9.5	780-840, 10.8-11.7Kb
Kawagama	660-730	8.2-8.90	670-790, 9-10 Kb
McLintock	680-700	7.5-7.8	670-740, 9-10 Kb
	*******		
e is no	notable	pressure or t	emperature difference b

Various subdomains although Opeongo, Kawagama and McLintock subdomains may

have equilibrated at slightly lower pressures. The lower pressures from Rosseau and PSSZ samples may not be significant because these were determined from gt-cpx-plag-qtz and gt-alsil-plag-qtz barometry which tends to give lower pressures than the preferred gt-opx-plag-qtz barometer. The results agree reasonably well with the lower range of Anovitz (pers. comm.) and when combined, suggest metamorphism at 700-750°C and 8-10 Kbars which straddles the ky-sill join in the petrogenetic grid presented in Figure 5.1. However this is not a major problem because the temperatures probably represent minimum estimates from re-equilibration and re-setting during cooling. Furthermore it is well known that sillimanite nucleates more easily than kyanite and the reaction Ky  $\rightarrow$  Sill probably requires a significant temperature overstep. Apparently this occurred in the PSSZ where at least some of the rocks re-equilibrated in the stability field of kyanite and muscovite.

## **Garnet** Peridotites

P.T estimates from these rocks are problematic because of variable Jd contents in pyroxene and probable re-equilibration down to around  $700^{\circ}$ C (Table 5.3a) during decompression and cooling. Similarly the geothermometer based on the Al-content of orthopyroxene (Gasparik & Newton, 1984) and Gasparik (1987) cannot be used to determine the initial equilibration temperatures because Al was exsolved from pyroxene in the form of spinel during decompression and reset temperatures of around  $700^{\circ}$ C are obtained. However, the graphical two-pyroxene thermometer of Lindsley & Anderson (1983) implies temperatures of 800-1000°C. Minimum pressures of 10-11 Kbars are suggested from the work of O'Neill (1981) for the transition from a spinel- to garnet lhezolite for the olivine composition Fo<sub>72-77</sub>. In addition, the presence of chrome in spinel raises the pressure stability of a spinel lhezolite and increases the likely equilibration pressure of the garnet peridotite.

# 5.4.5 FLUID EFFECTS

The P,T determinations all lie within the same broad range and there are no notable differences between the predominantly amphibolite and granulite facies terranes, within the level of uncertainty attatched to the various geothermometers and barometers. If this is indeed the case, some other factor must be responsible for the observed facies variation and the most obvious possibility is varying fluid activity. The

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significance of fluid-absent metamorphism was discussed by Thompson (1983), while Rubie (1986), Yardley & Baltazis (1985) and others described the important catalytic effects of having an aqueous fluid present. The significance of fluid composition in the granulite to amphibolite facies transition was noted by Buddington (1963) and Glassley & Sorenson (1980) who attributed the rapid transition from amphibolite to garnet granulite within a basic dyke to gradients in  $XH_{20}$  during metamorphism. This would also appear to be the case in the CGB: Muskoka domain {including Go Home, Rosseau and Seguin subdomains) contains relict granulite facies assemblages but is composed of predominantly amphibolite facies migmatitic gneiss, implying almost complete re-equilibration with an aqueous fluid during migmatisation. In the dominantly granulite facies terranes, the water activity must have been reduced and possibly internally buffered by retrogressive reactions. This is discussed in more detail in Chapter 6. section 6.6 where local variations in fluid activity are inferred on the scale of metres.

Significant low temperature retrogression and back-reaction is uncommon in both the upper amphibolite and granulite facies assemblages. This implies that they remained closed to later infiltrating fluids which would enhance reaction kinetics and promote further re-equilibration. Thus slow rates of reaction and diffusion in a dessicated crust favoured the metastable preservation of granulites. peridotites and coronite metagabbros during uplift.

# 5.4.6 DISCUSSION

Earlier work in the southwest Grenville Province by Chesworth (1971) inferred a general pressure increase from the Central Metasedimentary Belt (CMB) towards the Grenville Front. This was further substantiated by the quantitative work of Anovitz & Essene (1986) who estimated pressures of 4-6 Kbars from assemblages in the Frontenac axis in the Central Metasedimentary Belt (CMB), near the border with the U.S.A. (Fig. 2.1) which increased northwards, towards North Bay (10-11 Kbars) and then decreased in the direction of the Grenville Front; their corresponding temperature estimates form a broad thermal high, reaching  $800^{\circ}$ C NE of Parry Sound (Fig. 2.1). Within the CGB they infer a small pressure increase between the CMB and CGB but, in agreement with the present study, did not find large pressure discontinuities within the subdomains of the CGB. However

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they suggested that small thermal discontinuities may have existed and further that these could be responsible for the observed facies changes. Taken together this implies that the major crustal movements responsible for the stacking of the various subdomains occurred before or during the final metamorphic equilibration, although assemblages in the PSSZ apparently record further reaction during uplift. This is consistent with inferences from field observations in Huntsville subdomain (Nadeau, 1985; Chapter 3, this study) where many of the fine grained granulite facies assemblages from a broad ductile shear zone, were ascribed to annealed mylonites.

## P-T-time path of Metamorphism: qualitative model

Newton & Perkins (1982) proposed that crustal thickening during continental collision, as in the present-day Tibetan Plateau, was the primary tectonic mechanism responsible for the common clustering of regional granulite facies metamorphism at around 8 Kbars. This should produce P-T-t paths compatible with thrusting models of England & Thompson (1984) and Thompson & England (1984). However P-T paths are difficult to evaluate in granulites because the prograde and possibly peak conditions are nearly always lost during subsequent re-equilibration. The retrograde P-T path can be outlined to a certain extent by considering rim Bohlen et al. (1985) used this technique on Fe-rich garnet COmpositions. rims in the Adirondacks to infer near-isobaric cooling for 200-300°C before decompression. They related the additional heat supply to magmatic accretion. Similarly Ellis & Green (1985) proposed approximately isobaric cooling for the Napier complex. Antarctica and similarly related this to a magmatic component in the heat flux. Furthermore Bohlen et al. (1983b) pointed out that the inferred pressures for upper amphibolite and transitional granulite facies are similar to pressures obtained from granulites and garnet granulites. Based on this, they suggested that the formation of granulites depends on a temperature increase that they equated with magmatism. If this were also the case in the CGB, the magmatism must postdate the main tectonic movements. However this proposal ignores the additional complication of varying fluid activities during metamorphism which may be an equal if not more important control on facies variations at upper amphibolite and granulite grades of metamorphism. Mineral zoning has been observed in several samples from the CGB (Table 5.2) and consistently involves more Fe-rich garnet rims and reverse zoning in plagioclase. If rim compositions are assumed to be in equilibrium (note

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that pyroxene is not significantly zoned and probably re-equilibrated to a greater extent than garnet), then the P,T estimates on Figure 5.8 are obtained. These are very poorly constrained but do support down-temperature, down-pressure re-equilibration rather than near-isobaric cooling. This is consistent with decompression and cooling during isostatic uplift although the present data cannot rule out a magmatic component in the heat flux. Relatively rapid uplift rates of approximately 0.04-0.08 mm a<sup>-1</sup> were proposed by Berger & York (1981), in the Haliburton area of SW Grenville province, for the first 200 Ma. after the culmination of the Grenvillian orogeny (ca. 1000 Ma.), using K-Ar geothermometry. Uplift then slowed considerably until the area was finally exposed during Ordovician times.

FIGURE 5.8: Schematic P-T path for the CGB. A - estimates from this study; B - Anovitz pers. comm. Symbols refer to estimates from rim compositions in various subdomains (key as in Fig. 5.1).



# 5.5 CONCLUSIONS

The preferred tectonic mechanism responsible for metamorphism in the CGB involves re-equilibration by continuous exchange reactions, at 8-10 Kbars and 700-750°C in the mid- to lower crust, after crustal thickening during the culmination of the Grenvillian orogeny. Cation exchange by continuous reactions was relatively rapid and eliminated earlier equilibrium partitioning and was subsequently responsible for modifying rim compositions until temperatures dropped to around 550-600°C. Local variation in fluid activity was probably responsible for the observed granulite and upper amphibolite facies variations.

coronite metagabbros, garnet Disequilibrium texture in the peridotites and sapphirine-bearing assemblages were preserved by the slow kinetics of discontinuous reactions and record an earlier history. This is discussed further in Chapters 6 and 8, but it is unlikely that the whole terrane was originally at the pressures inferred from the boudins of garnet peridotite (this chapter) or sapphirine-bearing rocks (Chapter 8), and then underwent re-equilibration at 8-10 kbars. Instead the boudins were probably tectonically emplaced into their present position, where the undoubtedly higher pressures represent the lower crustal depths to which the shear zones were able to sample and incorporate material. This is further substantiated by the coronite metagabbros which were emplaced at around 1200 Ma. and preserve initial reactions that apparently took place at pressures that never exceeded 10-11 Kbars, during cooling from magmatic temperatures.

In the next Chapter the petrology of coronite metagabbros is discussed and the estimated P.T conditions obtained here for the host rocks are compared with those from various textural stages in the reaction history of the metagabbros. This implicitly assumes at least local equilibrium in the metagabbros and attempts to further constrain the P-T history in this part of the Grenville province, during the latter part of the Grenvillian cycle (ca. 1.2-1.0 Ga.).

# CHAPTER VI

# THE PETROLOGY OF METAGABBROS

## 6.1 INTRODUCTION

Chapters 2 and 3 discussed the field relations of anorthositic and gabbroic fragments in the structural domains and marginal shear zones within the Central Gneiss Belt. The gabbros are medium to coarse grained and were probably originally intruded as dyke- or sill-like bodies into a pre-existing gneissic basement. The depth of emplacement is not known, but during the Grenvillian orogeny (ca. 1.1-1.0 Ga.) they became fragmented under amphibolite and granulite facies conditions. They behaved as relatively rigid blocks within a more ductile gneissic matrix and as a result, the interiors of larger boudins are remarkably well preserved and it is possible to trace the evolution of the igneous fabric through a complex, multi-stage reaction history. This is the subject of this Chapter.

The initial reactions recorded in the metagabbro mineralogy are represented by coronas, separating plagioclase from olivine or opaque oxide. It is widely believed that olivine coronas have a subsolidus origin, forming as the rocks leave the olivine-plagioclase stability field and because dP/dT slopes for the reactions are positive (Fig. 6.1), they result from either a decrease in temperature or an increase in pressure, viz: (1) slow cooling at depth, promoting corona growth; (2) intrusion at moderate depths, followed by an increase in pressure during crustal thickening; or (3) a combination of (1) and (2). This chapter presents evidence in favour of slow cooling from magmatic temperatures for the early symplectite-forming reactions whereas, subsequent thrusting and about textural reworking by reaction, crustal thickening brought recrystallisation and deformation, and led to the reconstitution of the metastable corona structures into mafic two-pyroxene granulites or garnet This Chapter outlines the textural evolution and discusses amphibolites. the externally imposed controls on the reaction history, including P,T and fluid composition; internal kinetic controls on early corona-forming reactions are discussed in Chapter 7. The Chapter is divided into three

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FIGURE 5.1: Schematic P-T paths for different possible modes of origin for coronites: (1) thrusting and prograde metamorphism; (2) subsolidus cooling from magmatic temperatures; (3) a combination of (1) and (2), i.e. cooling during crustal thickening.



FIGURE 6.2: Geochronological results obtained in the isotope labs of the Canadian Geological Survey. Regression analysis of baddeleyite from concordant zircon has an upper intercept of \$\sigma\$ 1180 Ma. (Davidson pers. comm.)



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parts: part A describes the metamorphic textures and previous work on corona-forming reactions; part B, the mineral chemistry and part C, a theoretical and P-T evaluation of the multi-stage reaction history.

# 6.1.1 GEOCHRONOLOGY

Primary baddeleyite has been identified in the metagabbros (Davidson pers. comm.) and commonly is overgrown by zircon which may in turn act as nucleation sites for garnet  $\pm$  spinel growth (Plate 6.2c,d). U-Pb dates have been obtained for both baddeleyite and zircon in the isotope laboratories of the Canadian Geological Survey. The zircon ages are consistently ca. 1045 Ma. and lie on concordia, but baddeleyites are discordant (Fig. 6.1). Combining the two sets of data produces an upper intercept of ca. 1200 Ma. (Van Breemen pers. comm.), which could be interpreted as the age of intrusion. It is not known whether the zircon overgrowths are coeval with early corona growth, or are part of the later metamorphic reworking. However they are commonly mantled by monomineralic garnet growth is correlated with the prograde metamorphic evolution (section 6.2), zircon too probably grew during prograde metamorphism by reactions such as:

Bd Plag Fluid 3.5Zr0<sub>2</sub> + 2.5Ca <sub>4</sub>Na <sub>6</sub>Al <sub>1.4</sub>Si <sub>2.6</sub>0<sub>8</sub> + 2.375Mg0 →

 $3.52rSiO_4 + CaMg_2Al_2Si_3O_{12} + 0.375MgAl_2O_4 + 0.75Na_2O_7r$  Gt Sp Fluid

# PART A

# 6.2 PETROGRAPHY

This section describes the detailed textural history of the metagabbros and provides a framework for the P-T estimates and graphical analysis of reactions considered in section 6.5 to 6.9. The early reactions between olivine and plagioclase resulted in a variety of zonal mineral sequences (Table 6.1, stage I and Table 6.3, this study). Two examples are shown in Plate 6.1. The first consists of the assemblage opxcpx-amph-(amph-gt) symplectite (Plate 6.1a), while the others portray the more common corona composed of opx-cpx-(cpx-gt) symplectite (Plate  $\delta.1b-d$ ). The coronas are disequilibrium features brought about by mass transport where the establishment of local equilibrium along chemical potential gradients (Korzhinskii 1959; Thompson 1959), eliminated incompatibilities between adjacent minerals and led to the segregation of minerals into layers, each characterised by a mineral assemblage that is compatible, i.e. in equilibrium, with the layer assemblage bounding it on either side.

Similar coronas were described by Murthy (1958), in terms of subsolidus changes in crystal structure, whereby reactions resulted in lower energy configurations of coexisting Si,Al-O tetrahedra. This probably involved the minimum amount of structural reorganisation (i.e. min. entropy,  $\Delta s$ ) and resulted in the rearrangement of independent SiO<sub>4</sub> olivine tetrahedra into pyroxene chains. Amphibole has a double chain structure and is most like the continuous plagioclase framework. However the formation of garnet is likely to be the most energetic step with a high activation energy, requiring complete disruption of the plagioclase framework and a change in the Central Gneiss Belt (CGB), primary clinopyroxene does not participate in any early reaction with plagioclase; i.e. its structure is intermediate between olivine and plagioclase resulting in lower interfacial energy at a plagioclase further in Chapter 7.

# 6.2.1 ORIGIN OF CORONAS - STAGE I

Joesten (1986) highlighted the problem of determining whether coronas form by sequential or simultaneous growth. He proposed a magmatic, followed by annealing origin for coronas from Risör. Norway. A sequential origin is responsible for the garnet-bearing coronas in the Adirondacks, New York State. Here an early spinel-clinopyroxene symplectite was incompletely replaced by a garnet layer (Whitney & McLelland, 1973; Plate 5.2b). Similar coronas were described in Norway by Griffin & Heier (1973) and Gardner & Robins (1974). These authors describe the inward replacement of the spinel symplectite by garnet which advanced from both the pyroxene

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# PLATE 6.1

- A: Olivine corona consisting of opx-cpx-amph-(amph-gt) symplectite in sample 84DMS-13a. The plate shows a discontinuous garnet layer adjacent to spinel-clouded plagioclase. Note the symplectite and garnet layers cut across the spinel clouding.
- B: An Opx-cpx-(gt-cpx)sym corona around olivine. Note primary apatite (Ap) which just penetrates the clinopyroxene layer and primary biotite at the clinopyroxene-symplectite contact (85DMSR-82).
- C: Olivine corona with an outer garnet-symplectite, adjacent to a corona containing a dark outer layer comprising a spinel-bearing symplectite (85DMSK-10). Note the discontinuous, radial distribution of spinel-clouding in plagioclase adjacent to the garnet-symplectite corona.
- D: Greater magnification showing the fine grained nature of the (gt-cpx) symplectite in Plate 6.18.



0.125mm

By analogy with Risör, Joesten (1986a) suggested a magmatic origin for the early spinel-bearing symplectite in the Adirondacks, followed by later subsolidus growth of garnet. However the textures in Adirondack samples on loan to the author by P. Whitney, imply that the spinel symplectite was not the product of magmatic reaction and further, that the coronas resulted from wholly subsolidus, sequential processes. for example, the Adirondack samples are generally richer in primary clinopyroxene which commonly encloses olivine grains and when this occurs a fan-shaped spinel symplectite forms at the pyroxene-plagioclase interface (Plate 6.2b) although, as in the CGB, primary clinopyroxene alone does not react with plagioclase. If this was a rare observation, it could reflect connection with magmatic fluid outside the plane of the section. However it is a common feature and necessitates subsolidus diffusion through primary clinopyroxene, from the olivine to the plagioclase interface.

The texturally unevolved coronas in the CGB are represented by Stage I in Table 6.1 where the samples are arranged in order of increasing corona development. The spinel-bearing symplectite is rare and occurs sporadically in only three samples (\* samples in Table 6.1), where otherwise (cpx-gt) is the dominant intergrowth. The spinel-bearing corona is most common in 85DMSK-10, but has no orthopyroxene layer and clinopyroxene occurs adjacent to olivine; i.e. ol/cpx+amph-(spin sym)/plag. In addition the spinel symplectite is formed preferentially when olivine is partly enclosed or adjacent to primary clinopyroxene, although the latter by itself does not react with plagioclase. Both symplectite types coexist metastably (Plate 6.1c) and there is no evidence that the clinopyroxene symplectite replaces the spinel symplectite. Both consist of fine grained intergrowths (Plate 6.1d), and the parallel-sided vermicular (gt-cpx) intergrowth common in the Adirondacks, is a rarer morphology. In the Adirondacks the spinel-bearing symplectite is retained in samples which show moderate degrees of recrystallisation. In contrast, most of the texturally unevolved coronites in the CGB (Stage I) do not show any evidence of ever possessing a spinel-bearing symplectite.

A magmatic origin for olivine coronas in the CGB can be discounted on the basis of liquidus compositions discussed in Chapter 4. The metagabbros are transitional between tholeiites and alkali basalts, generally just nepheline-normative and high in normative olivine and plagioclase. During

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# PLATE 6.2

- A: More evolved coronite. Garnet has advanced sub- to euhedrally into plagioclase and inwards at the expense of the symplectite layer. The plagioclase has started to recrystallise and the spinel to aggregate into discrete blades, aligned along crystallographic directions, parallel to the twin planes.
- B: Olivine corona enclosed in primary clinopyroxene, from Jay Mtn. in the Adirondacks. The olivine has generated a (spinel-cpx) symplectite in the adjacent plagioclase by mass transfer through primary clinopyroxene. Isolated primary clinopyroxene shows no reaction with plagioclase. The spinel-bearing symplectite was subsequently partially replaced by monomineralic garnet, which advanced from both the clinopyroxene and plagioclase interfaces.
- C: Back-scattered image of baddeleyite surrounded by a zircon overgrowth (photograph courtesy of A. Davidson).
- D: High magnification transmitted light image of dark baddeleyite core with a zircon overgrowth surrounded by a discontinuous garnet layer (photograph courtesy of A. Davidson).



TABLE 5.1: Textural evolution of metagabbros (underlined samples have been analysed by microprobe - appendix III).

STAGE I

where  $\mathcal{L}_{\mathbf{p}}$  is a charge specific  $\mathcal{L}_{\mathbf{p}}$  is the  $\mathcal{L}_{\mathbf{p}}$  is a charge specific  $\mathcal{L}_{\mathbf{p}}$  is  $\mathcal{L}_{\mathbf{p}}$  is a charge specific  $\mathcal{L}_{\mathbf{p}}$ 

 I.P. LET A. C. M. H. S. Marked Market Ma Market Ma Market Ma Market M Market Mar

85DMSR-82 opx-cpx-sym; wide opx layer, very little mono-gt and negligible rextalln in plagioclase.

(1) A set of the se

* <u>B5DMSK-10</u> Dpx-cpx-(gt-cpx)sym and cpx+(cpx-spin)sym. Zonal	spinel-clouding in plagioclase around olivine coronas, very little
l biot in op coronas.	
I	
<u>84DMS-13A</u> opx-cpx-amph-sym <u>+g</u> t. Slightly more clearing of p	lagioclase.
1	
* <u>85DMS-8</u> rare spinel-bearing coronas, few small gts nucleat	ing within plag laths.
85DMSR-28	
<u> </u>	
<u>86DMS-18</u> Coronas still relatively narow, plagioclase laths	still retain fine dusting with spinel.
* 85DMS-7	
85DMS-6 Few amph-bearing coronas; only olivine cores remain	n; some nucleation of gt and incipient rextalln of plag.
<u>85DMSR-30</u> Dl <u>+</u> opx-cpx-(gt-cpx)sym-gt	
85DMSK-2 opx-cpx+amph-sym+gt; Dusty plag cores remain, mod	erate annealing of spinel $\Rightarrow$ fine grained spinel blebs and gt
development within laths.	
1	
1	STAGE II
1 MET	AMORPHIC REWORKING WITH OLIVINE STILL PRESENT
CONTINUED DIFFUSION-CONTROLLED GROWTH	1
RESULTING IN OLIVINE LOSS	85DMSH-4D1,4D2 opx-cpx <u>+</u> moat-sym <u>+</u> gt; initial plag moat fm;
1	I relict spinel-dusting cores of plag laths.
85DMSR-33 A little plag rextalln and growth	1
<u>84DMS-19A</u> of small garnets. A little moat formation	<u>85DMSH-46</u> Wide sym <u>+g</u> t layers; annealing of spinel into
and some subhedral gt growth from sym.	85DMSH-4E blades. Moat best developed when coronas cored by
I	<u>85DMSH-101C</u> opx (ol gone); monomineralic gt layer well
METAMORPHIC REWORKING - STAGE II	established; incipient corrosion of prim cpx.
I	1
85DMSR-82A Only cloudy plag cores left; incipient	85DMSK-3 Large amount of incipient rextalln in plag and only
I rextalln, annealing of spinel and gt	850MSK-9A cores retain spinel; blebby amph-gt around prim cpx.
I growth within plagioclase.	1
1	85DMSH-4B Lobate and seriate grain boundaries to plag laths;
85DMSK-6 No sym left and early plag moat formation;	I olivine preserved preferentially when partly enclosed
more advance rextalln of plag laths,	l in prim cpx.
annealing of spinel and gt formation.	1

#### TABLE 5.1 (Stage II cont'd)

# <u>85DMSH-4C</u> Rare olivine kernals; plag moat well established between cpx-gt with minimal symplectite.

As the coronas evolved the spinel clouding annealed into discrete spinel blades. There is greater gt growth at the expense of the symplectite and plagioclase laths. The nucleation of gt within plag laths also increases and plagioclase progressively rextallises. A plag moat formed between cpx and gt+sym and eventually there was LOSS OF OLIVINE.

#### STAGE IIa

# METAHORPHIC EVOLUTION IN COARSE-GRAINED CORONITES WHERE WIDE CORONAS HAVE FORMED, BUT OLIVINE

IS RETAINED BECAUSE OF ITS LARGE SIZE.

<u>85DMSA-8B</u> Vestiges of (gt-cpx) symplectite retained;

I relict spinel-clouded cores in plag laths

which have rextallised margins. Prim cpx

just beginning to rextallise.

- <u>850M-230</u> (Gt-cpx) sym still present but plag laths show the effects of dynamic rextalln, enhancing annealing of the spinel dust (Plate 6.).

#### LOSS OF SYMPLECTITE GARNET

1

84DMSA-(X-1) Opx<u>+</u>(opx-gt)sym-moat-gt; discrete spinel B5DMSA-11 grains present in central parts of plag 84DMSA-11D' laths: some rextalln and opx formation

I around prim cpx which is beginning to lose
I the ilmenite dust and is being retrogressed

at its margins.

<u>84DMSA-11F</u> More extensive development of subhedral gt

- 1 within rextallising plag laths. Plag cores
- i still contain some relict clouding and
- 1 discrete spinel grains.
- 1

85DMSH-101D Moderate rextalln of plag laths and extensive gt 85DMSK-13 nucleation/growth as fine grained aggregates and 85DMSR-31B subhedral grains within relict plag laths; plag

cores still contain blades of spinel + some corundum. prim cpx loosing ilmenite dust → discrete ilmenite inclusions; cpx margins becoming "blebby".

#### LOSS OF SYMPLECTITE GARNET

85DMSH-106 Wide plagioclase moat and non-symplectitic garnet; 85DMSH-109 garnet growth along rextallised plag grain bound-85DMSH-5F aries and within relict plag cores. Prim cpx shows

some rextalln and gt growth in adjacent plag, often
 extensively pseudomorphing relict plag laths.

85DMSH-101B Extensive formation of monomineralic garnet rims

I and opx coronas and prim cpx.

85DMSH-37 Plagioclase margins extensively rextallised. Prim 85DMSH-2A cpx shows greater loss of ilmenite dust and more re-84DMS-157 xtalln at its margins. Relict laths contain rare sp.

```
TABLE 5.1 (Stage II cont'd)
                                                                         Ł
  84DMSA-13M 01-opx-wide moat-thin discontinuous gt:
  85DMSA-13A No clouding left in plagioclase, all spinel
                                                                          1
  85DMSA-11A in form of discrete grains, along within gt,
             corundum and cox, within rextallising plag.
      Ł
84DMSA-138 Greater plag rextalln and growth of gt, cpx
            and biot inclusions; plus a liitle spinel. Gt
            also froming in sub-ophitic plag adjacent to
      T.
            prim cpx: the latter rextallising and loosing ilm.
                                                                     85DMSH-86
 <u>B5DMSA-165</u> Ol+opx+cpx-moat-gt; moat commonly adj to oliv.
 85DMSD-68 Extensive gt formation within rextallising plag.
            but lath cores still contain some spinel. Samples
            finer grained than above examples.
LOSS OF OLIVINE
      1
85DMSA-13P Plagioclase lamination
850MSA-1648 Opx-moat-gt; prim cpx and plag show greater
84DMSA-11L rextalln and contain relatively large sub-
85DMSB-1D hedral gt: very rare spinel inclusions.
84DMSA-118 Fine grained, chilled margin samples. Plag
84DMSA-11C almost totally reconstituted resulting in
            subhedral garnets in a granoblastic mosaic
            with plagioclase. Prim cpx shows moderate
            rextalln and extensive retrogression with
            some clearing of ilm dust. Opx aggregates
            left as vestiges of olivine coronas.
    RECRYSTALLISATION OF PLAGIOCLASE COMPLETE
```

850MSR-83 spinel grains and amphibole retrogression of mafic

minerals has been variably superimposed on the reaction textures.

85DMSH-18 Only traces of spinel within relict plag laths 85DMSR-22 which contain relatively large subhedral and blebby garnets.

<u>85DMSH-84C,84</u> Only poikiloblastic opx-plag cores to coronas

with wide plagioclase moats separating opx from gt. Prim cpx has corroded margins and has begun to rextallise. Plagioclase almost completely reconstituted into a granoblastic mosaic, but some fine-grained spinel was retained as small stals at nodes in the plag mosaic in DMSH-84.

RECRYSTALLISATION OF PLAGIOCLASE COMPLETE

The primary mineralogy and coronite affinity is now shown by the relict ilmenite dust in prim cpx and the biot+amph-gt coronas around ilmenite. Table 6.2 continues the textural evolution for prim cpx, ilmenite coronas and relict opx aggregates and documents further metamorphism and dynamic recrystallisation which eventually led to totally reconstituted two-pyroxene granulites or gt amphibolites.

crystallisation, olivine-plagioclase-opaque oxide was followed by titaniferous clinopyroxene, biotite, apatite and in some cases, late-stage zircon and baddeleyite. Thus the liquids became progressively enriched in incompatible elements. If a magmatic origin is inferred for corona cpx, it should also be rich in Ti. This is not the case and the olivine coronas do not reflect the liquid evolution. In addition there is no magmatic orthopyroxene while magmatic, late-stage apatite and biotite are commonly observed at, or just penetrating, the clinopyroxene layer at the contact with the symplectite (Plate 6.1b). The latter suggests that the garnet symplectite was not the product of high pressure magmatic reaction and furthermore, that the original olivine-plagioclase contact was located near the outer edge of the clinopyroxene layer.

# Textural changes during Stage I

age of initial corona growth in the CGB metagabbros and its The relation to both the intrusive age (ca. 1200 Ma.) and metamorphic age (ca. 1045 Ma.) has not been unequivocally determined. However textural evidence suggests an extended reaction history which is summarised in Table 5.1. During stage I the coronas developed under diffusion-controlled growth (Chapter 7). However textures in samples preceding 85DMSR-33 and 84DMS-19 in Table 6.1, imply divergent evolutionary trends with the right hand fork marking the onset of metamorphic reworking (Stage II). The latter is characterised by increasingly more aggregation of spinel dust into discrete spinel blades and greater development of monomineralic garnet layers, which grows subhedrally outwards into plagioclase and inwards, at the expense of the symplectite layer (Plate 6.2a). In contrast, even though olivine has reacted out in samples 84DMS-19 and 85DMSR-33, there is very little evidence of any spinel-annealing within plagioclase, and a well developed symplectite is still present. This suggests that these samples represent the most advanced stages of diffusion-controlled growth which allowed the complete replacement of olivine by a radial orthopyroxene core. Metamorphic reworking (Stage II) did not result in the removal of olivine in samples of similar grain size, until quite advanced stages of reaction when a sodic plagioclase moat developed between monomineralic garnet rims and the pyroxene core (Stage II, Plate 6.3a). Based on these observations, it is proposed that there was an independent, predated the prograde metamorphic diffusion-controlled path which reworking, the latter requiring more energy to nucleate and grow extensive garnet layers and being superimposed at various "frozen" stages in the
development of the diffusion-controlled structure. This early history probably occurred during slow cooling, and the reactions may have stopped when the coronas became too large and the chemical-potential gradients too small to drive significant diffusion. Perhaps more importantly, diffusion rates decrease exponentially with temperature, so that diffusion rates became so slow and effectively stopped at some critical temperature, preserving metastably the delicate corona structures listed under Stage I of Table 6.1.

A subsolidus cooling mechanism can account for the rarity of a spinel symplectite if the CGB gabbros were intruded at greater depths than the Norwegian or Adirondack examples; higher pressures allowing the spinel field (Figs. 6.1, 6.18) to be rapidly passed through with very little, if any reaction. Metagabbros within the Central Metasedimentary Belt (Grieve & Gittins, 1975) lend further support to depth-control on corona mineralogy. This is a lower pressure terrane and here an (amph-spin) symplectite developed in coronas around olivine. This is also the case in the Adirondacks where the spinel symplectite is much more common in the lower pressure Adirondack Lowlands (Whitney & McLelland, 1973); Bohlen et al. (1985) estimated pressures of 6-7 kbars in the Adirondack Lowlands compared with 7-8 Kbars in the Adirondack Highlands. In addition the spinel symplectite is associated with calcic plagioclase ("An<sub>ee</sub>) which is the primary magmatic, normative composition, whereas similar to plagioclase associated with garnet coronas is consistently more sodic, at around An<sub>ae</sub> (McLelland & Whitney, 1980; Whitney & McLelland, 1973); the formation of more sodic plagioclase being broadly consistent with greater of origin for garnet-bearing coronas. Spinel-clouding in depths plagioclase is less intense in the garnet-free Adirondack samples so that it is unlikely that clouding is a primary exsolution phenomena and instead, is maximised during corona growth in the garnet stability field. in the lower pressure Central Similar inferences be can made Metasedimentary Belt where Grieve & Gittins (1975) reported spinel-bearing coronas adjacent to primary, calcic plagioclase (An<sub>62-68</sub>). The depth control on corona mineralogy applies equally to the prograde metamorphic origin, but it seems unlikely that the spinel-field could be overstepped preferentially in the CGB, as opposed to other high pressure terranes. Furthermore, the correlation between intense clouding and increasing degrees of corona development was also noted in Norway by Emmett (1982). Here rapidly chilled, marginal samples have poorly developed coronas and only faintly clouded plagioclase and this similarly favours an origin by

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slow, subsolidus cooling.

In summary the variety of corona-types developed in Stage I reflect subsolidus metastability rather than magmatic reaction and the delicate coronas once formed, including the very rare spinel-bearing symplectites, protected olivine-plagioclase from further reaction and re-equilibration. The early coronas resulted from diffusion-controlled growth, probably initiated during cooling when there may have been some residual liquid around (Ashworth, 1986). Later metamorphic reactions were multi-stage and these are discussed in the next section.

#### 5.2.2. PROGRADE TEXTURAL EVOLUTION - STAGE II & III

This section describes the textural changes brought about by granulite and amphibolite facies reworking, locally accompanied by shearing and cataclasis.

#### Stage II

The textural evolution of metagabbros during Stage II is summarised in Table 5.1. This represents the early textural reworking which gradually broke down the macroscopic, sub-ophitic fabric (Plate 3.3b). At first this involved progressive annealing and aggregation of spinel dust, incipient and increasing recrystallisation of plagioclase and growth of small garnets, the latter nucleating within both plagioclase mosaics and relict plagioclase laths. The orientation of the spinel blades parallel to twin planes in plagioclase (Plate 6.3b) suggests that the aggregation of spinel occurred under crystallographic control, presumably representing a minimum structural rearrangement of the plagioclase framework. At the same time the symplectite layer was progressively replaced by monomineralic garnet which also advanced sub- to euhedrally outwards into plagioclase (Plate 6.2d). The growth of low energy, euhedral faces is a relatively slow process and suggests that the reactions were no longer diffusioncontrolled (Tracy & McLellan, 1985). Instead the interface mechanism, involving dissolution of plagioclase and nucleation/growth of garnet became rate-controlling. As mentioned earlier, it probably requires a large activation energy to bring about the change in coordination of Al<sup>3+</sup> from plagioclase to garnet and as a consequence, it is likely that only prograde metamorphism could provide sufficient energy to grow extensive garnet rims.

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## PLATE 6.3

- A: Plagioclase moat between a pyroxene core <u>+</u> olivine and monomineralic garnet layers. Relict plagioclase laths contain discrete spinel blades.
- B: Relict plagioclase laths containing annealed spinel blades oriented along crystallographic directions in the plagioclase framework. Garnet has also nucleated with plagiolcase and the adjacent clear inclusions are probably corundum (crossed polars, XPL).
  - C: Strain-induced annealing of spinel dust in a sample from northern Kiosk domain (85DM-230). The plagioclase lath has been bent and has started to recrystallise into a fine grained mortar texture.
- D: Olivine-opx<u>+(opx-gt)</u> sym separated from monomineralic garnet by a plagioclase moat. Collected from Opeongo subdomain (84DMSA-11F).



0.125mm

Just before the symplectite layer became exhausted, a sodic plagioclase most began to develop between pyroxene and monomineralic garnet layers. McLelland & Whitney (1980) suggested two reasons for most formation: (1) primary igneous zoning in plagioclase where garnet growth was confined to relatively calcic compositions towards the core of plagiolcase laths, somewhat removed from the original olivine-plagiolcase contact. (2)  $\Delta V$  of garnet-forming reactions is negative and converts plagioclase to more sodic compositions. The latter is accompanied by a small volume increase so that to approximately conserve volume, the albitic plagioclase is displaced inwards to replace the volume left by the advancing garnet layer. The proposal for volume control is supported here because a plagioclase most only develops when there has been extensive garnet growth.

## Stage IIA

During Stage II olivine disappeared in medium-grained metagabbros by sample 85DMSH-4C. However, large olivines in coarse-grained samples persisted to more advanced stages of reaction. Examples of this are listed under Stage IIa in Table 6.1 where a relict symplectite is only preserved in the first two samples. All the samples, apart from 85DM-230 (NE Kiosk domain, Fig. 1.1) and 85DMSD-68 (Kawagama zone), come from Opeongo subdomain. Sample 85DM-230 has been subjected to dynamic metamorphism which promoted the annealing of spinel along kink bands within strained plagioclase and resulted in fine-grained spinel blades within mortartextured plagioclase (Plate 6.3c). Otherwise the coronas in this sample are remarkably well preserved and suggests that the strain was rapidly applied, without significant hydration or time to promote extensive metamorphic reworking.

The other textural changes recorded in these samples are similar to Stage II and involved the formation of a plagioclase moat and monomineralic garnet rims. coupled with progressive recrystallisation of plagioclase. However there are several mineralogical differences in samples from Stage IIa. Firstly clinopyroxene as well as garnet nucleated within plagioclase laths and secondly, a greater variety of corona-types is present. Notably a clinopyroxene layer is uncommon in Fe-rich samples and instead, orthopyroxene or an (opx-gt) symplectite (e.g. 84DMSA-11F. Plate 6.3d) developed adjacent to a plagioclase moat. In addition, 85DMSD-68 and 85DMSA-165 show no evidence of ever developing symplectite-

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bearing coronas; olivine is typically preserved in direct contact with the plagioclase moat with very little pyroxene or (opx-gt) symplectite between them. Furthermore the olivine grains have not been corroded (i.e. original opx+cpx layers have not been resorbed) and olivine is intergrown directly with sodic, recrystallised pseudomorphs of plagioclase laths (Plate 6.4a). Thus olivine appears to have simply equilibrated with more sodic plagioclase by a garnet-producing reaction. This is a useful thermobarometric assemblage and is discussed further in section 6.8.

Eventually in both Stages II and IIa, plagioclase laths completely recrystallised into granoblastic mosaics and wide plagioclase moats became established between garnet layers and pyroxene-plagioclase cores (Plate 5.3a & 5.4b). However the recrystallised fabric and relict primary clinopyroxene still define a macroscopic, sub-ophitic texture which was retained until the onset of deformation and/or loss of primary clinopyroxene. This is Stage III.

## Stage III

This is documented by the destruction of primary clinopyroxene and the loss of a macroscopic igneous fabric. The evolution is complex and reflects the interplay of different grades of static metamorphism, localised deformation and varying  $aH_2O$ . In the Huntsville area static metamorphism in one case resulted in almost complete garnet pseudomorphs of plagioclase laths (85DMSS-1B; Plate 3.4b). Here primary clinopyroxene is still preserved but has been mantled by retrogressive amphibole.

The microscopic evolution is summarised in Table 6.2 and is best portrayed by metagabbros from the Huntsville and Seguin subdomains. With the possible exception of 85DMSK-10 (secton 6.4), primary clinopyroxene did not take part in the initial corona-forming reactions. However, during stages II and III, it became increasingly free of ilmenite inclusions and recrystallised with variable amounts of amphibole retrogression. In the early stages it recrystallised at the margins into a two pyroxene<u>+</u> plagioclase mosaic and then became progressively more poikiloblastic internally and crowded with plagioclase (Plate 6.4b). In one case the exsolution of plagioclase was crystallographically controlled (85DMSH-228; Plate 6.4c). In this sample the metamorphism resulted in  $\sim$  40% garnet development, accompanied by clinopyroxene, a little amphibole, opaque oxides, quartz and some plagioclase. This suggests a local reduction in water activity during metamorphism which together with extensive garnet

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## PLATE 6.4

- A: Sub-ophitic olivine adjacent to recrystallised plagioclase which separates olivine from garnet. There is very little corona pyroxene and when present it is poorly developed and discontinuous; Kawagama zone, 85DMSD-68.
  - B: Evolved, relict metagabbro where fine grained, granoblastic pyroxene-plagioclase cores represent the remnants of olivine coronas, and matrix plagiolcase has completely recrystallised into a granoblastic mosaic.
  - C: Evolved sample from Huntsville subdomain (85DMSH-228) where extensive garnet development at the expense of plagioclase has resulted in excess silica and quartz formation. Primary clinopyroxene has exsolved plagioclase under crystallographic control, parallel to the cleavage directions.
  - D: Garnet-spotted amphibolite showing relict poikiloblastic primary clinopyroxene being by hornblende.





TABLE 6.2: STAGE III evolution of metagabbros after recrystallisation of plagioclase.

HUNTSVILLE & SEGUIN SAMPLES 85DMSH-55 Ol-cpx-op-gt-amph-biot-plag; unusual ol-cpx-op cumulate with interstitial plag. Sodic moat 1 separates ol+opx+(opx-gt)sym from gt; ol commonly 1 in direct contact with sodic plag. Prim cpx shows 1 a little rextalln at margins and some retrogression. 850MSH-57 Opx-cpx-moat/amph-gt; Plag has just rextallised 850MSH-18G with spinel knots in cores of plag domains while garnet occurs towards the margins. 85DMSH-18D more extensive recrystallisation and clearing of 85DMSH-18A ilmenite dust in primary clinopyroxene. 850MSH-56 High degree of subhedral gt development within plagioclase mosaic. Beginning of cpx-plag mosaic at margins of primary cpx. 1 85DMSH-18I Clinopyroxene becoming poikiloblastic with further 85DMSH-18F development of 2 pyx-plag mosaics. 1 GREATER HYDRATION AND ANHYDROUS METAMORPHISM RETROGRESSION 85DMSS-18 Gt pseudomorphs 850MSR-38 more amph than S-18 1 85DMSH-22B gt-cpx-plag-qtz-op xtallographic exsoln of plag in relict prim cpx. 85DMSH-5A Sieve-like cpx core with amph retrogression on opx-plag mosaic ł. at margins.

#### OPEONGO SAMPLES 1 SHEARING DEFORMATION COMBINED DEEM AND METAMORPHISM t. 84DMSA-116 Mortar plag 84DMSA-8C Extensive cpx rextalln 84DMSA-2A few relicts of strained I some cox rextallo plag cores. op-amph-gt 84DMSA-13N Flattened op coronas and opx-cpx 84DMSA-98 Prim cpx mantled by 84DMSA-13A granular opx-cpx-plag aggregates. Prim cpx mantled by opx-cpx-amp + patchy amph retrogression 84DMSA-13C Gt only retained in 84DMSA-11A extreme shear defm resulting in gabbro cores of rextallised plag mylonite with cpx p/clasts domains. GARNETS BECOMING RARE 84DMSA-9A cpx-opx-amph-biot-op-plag-apat 84DMSA-13C' only cores of prim cpx left 84DMSA-9C replaced by opx-cpx-plag mosaics. A little gt in 13C<sup>2</sup>. 1 84DMSA(X-2) cpx-opx-amp-gt-plag-biot-ap-op 84DMSA-11A extensive amph retrogression and prim cpx replaced by flattened aggregates of opx-cpx Few gts in plag domains. LOSS OF ORIGINAL PRIMARY CLINOPYROXENE 1 84DMSA-138 opx-cpx-amp-bi-plag-op-ap-gt

very little gt.

1

850MSH-28 Only blebby pyx core reamain as Ł relicts of oliving coronas: i.e. (opx+plag)-moat-gt. 1 ŧ 85DMSH-15 Cpx more poikiloblastic and gt 85DMSS-1A beginning to aggregate into sub-85DMSH-5E spherical forms (incipient "spots"). Rextallised plag intergrown with cpx is starting to become optically continuous. 1 85DMSH-18C gt-cpx-amp-plag-op-biot; more aggregation of gt; cpx strongly retro-1 gressed. Macroscopic igneous fabric almost gone LOSS OF ORIGINAL PRIMARY CLINOPYROXENE t 1 85DMSH-18H opx-cpx-plag-gt-op MORE AMPHIBOLE anhydrous granulite 1 RETROGRESSION with some amph. 1 . 1 85DMSS-1C Vein-network opx-cpx-1 85DMSD-9 plag around hydrous Gt-spotted texture with 85DMSH-105 850MSH-101A sieve-like cpx intergrown t amp-biot-gt with plag plates. 1 85DMSD-62C Foliated granulite 1 opx-cpx-plag-gt-amp-op 85DMSH-102 Amph-plag-gt-opx-cpx-op. 84DMS-45A Amph-gt-plag-cpx-biot. 1 85DMSK-4 Amphibolite; plag-amph-biot-gt-gtz 1 84DMSA-13H extensive amph retrogression and higher prop of gt (5%) as "spots" in cores of plagioclase domains. growth, locked up  $Al_{20}$  and resulted in excess silica. This sample is unusual because typically extensive amphibole growth occurs around mafic minerals with little, if any quartz. Eventually all vestiges of primary clinopyroxene are lost and the metagabbros are represented by either garnet-spotted amphibolites, where sub-spherical garnet aggregates are separated from cpx-amp+biot by a sodic plagioclase moat (e.g. 85DMSH-101A, 105, 85DMSS-1A; Plate 6.6d), or two pyroxene-garnet granulites (85DMSH-18H), the latter exhibiting variable amounts of amphibole retrogression.

In Opeongo subdomain a systematic textural history cannot be drawn up because localised shearing deformation and fluid influx are variably superimposed on the static metamorphic reworking. However there is very little garnet in the evolved Opeongo or Kawagama zone metagabbros and the end-point of metamorphism is a two pyroxene granulite with varying amounts of amph+biot. The evolution is summarised on the right hand side of Table 6.2, where garnet is only preserved in the cores of recrystallised plagioclase domains immediately after plagioclase recrystallisation. As the metagabbros became further reconstituted garnet gradually disappeared. presumably reflecting differences in bulk composition, P,T or a upn between the Huntsville and Opeongo areas. This is discussed further in section 6.5. A few evolved samples still retain a little garnet in the cores of plagioclase domains and one sample (84DMSA-13H) has garnet porphyroblasts ( $\infty$ 5%), resembling the garnet "spots" in the Huntsville area. In outcrop, garnet has been lost preferentially around pegmatitic veins and shear zones, where fluid influx supplied alkalis promoting biotite growth. The localised shear zone development within the Opeongo metagabbros was discussed in Chapter 3, section 3.3 and resulted in a foliated. "clotted" fabric involving opx-cpx aggregates with or without relicts of primary clinopyroxene. In thin section (Table 6.2, samples 84DMSA-11G to 11A). plagioclase exhibits a well-developed mortar texture and in one extreme case, a gabbro-mylonite with primary clinopyroxene porphyroclasts has 6.5b). As before, primary clinopyroxene eventually formed (Plate recrystallises into a two pyroxene-plagioclase mosaic (Plate 6.5a), accompanied by varying amounts of amphibole and biotite retrogression. Furthermore, from Stage II onwards, pyroxene nucleated and grew within relict plagioclase laths eventually forming a granoblastic two-pyroxene granulite within the plagioclase matrix, wholly independent of primary clinopyroxene.

# 6.2.3 OPAQUE OXIDE CORONAS

Relicts of the primary opaque mineralogy are preserved in several of the coarser grained, unevolved samples. It comprised magnetite-ulvospinel (Mt-Usp) and ilmenite. During cooling magnetite exsolved ilmenite lamellae (Plate 6.5d) and less commonly spinel. Coronas around opaque oxides are ubiquitous and a variety of corona types has developed. In general these involve an inner layer of biotite adjacent to ilmenite (+ Mt) followed by amphibole and a (gt-cpx) symplectite or garnet layer adjacent to plagioclase (Plate 6.5c). However the width and mineralogy of individual layers is more variable than the olivine coronas but similarly, the symplectite is only present in the least evolved metagabbros and has disappeared by sample 85DMSH-4C (Table 6.1). In 85DMSK-10 and 85DMSK-2 the amphibole layer is absent and only a narrow biotite layer has formed between ilmenite and the (gt-cpx) symplectite whereas in other unevolved common assemblage is biotite+amphibole-symplectite. Primary samples, the biotite magmatic is present as a late, interstitial phase in the metaso corona biotite could also have a magmatic origin. This was gabbros for corona biotite in the unmetamorphosed and high-level Nain proposed dykes of Labrador (Wiebe, 1985; Chapter 4, section 4.3). A magmatic reaction would account for the variable size of the biotite layer, both one thin section and between samples; the amount of biotite within anv growth depending primarily on the K\_O content of the evolving liquid.

The textural evolution of the symplectite layer is similar to that of the olivine coronas and involved the progressive growth of garnet at the Of symplectite, although sometimes garnet disappeared expense the the corona assemblages encompass various entirely. As 2 result ilmenite+biot+amph+gt. In the coarse-grained samples combinations of (stage IIa), the outer symplectite-gt layers are only present in 85DMSA-8B and 85DM-230, while more evolved samples are dominated by ilmenite-biot-Eventually biotite may disappear, leaving ilmenite cores amph<u>+</u>moat+gt. rimmed by coarse-grained amphibole aggregates adjacent to recrystallised plagioclase. At the same time garnet either became randomly distributed within the plagiolcase mosaic, rather than localised around the coronas or as in the Opeongo samples, disappeared.

# PLATE 6.5

- A: Two pyroxene granulite with relict primary clinopyroxene, derived from coronite metagabbro in Opeongo subdomain.
  - 8: Gabbro mylonite with primary clinopyroxene porphyroclasts collected from a narrow internal shear zone within a gabbroic boudin in Opeongo subdomain.
  - C: Opaque corona in sample from Go Home subdomain (84DHS-19). Ilmenite is surrounded by biotite, Ti-hornblende and a (gt-cpx) symplectite
  - D: Relected light image of opaque oxide grain showing a highly reflective magnetite-ulvopspinel host with both fine grained ilmenite lamellae and discrete ilmenite rods.



0 · 125 mm

# 5.3 PREVIOUS WORK ON CORONA-FORMING REACTIONS

This section presents a short review of previous work on the reaction mechanisms and P-T stabilities of coronas. Coronas are found in a range of basic rock types ranging from ultramafics to gabbros and anorthosites. Many examples have been described in the literature between the following mineral pairs: ol-plag (Table 5.3); opaque-plag; opx-plag; opaque-cpx (Van Lamoen 1979). The general consensus on ol-plag coronas supports a subsolidus origin although, as discussed previously (section 5.2.1), Joesten (1986) favours a magmatic origin.

Coronas are metastable and many subsequent tectonic modifications have been described in the literature: prograde, granulite-facies reworking resulted in garnet-producing reactions (Griffin & Heier, 1973; Whitney & McLelland 1973; this study), while mineralogical changes caused by pressure increases up to eclogite grade were documented by Mørk (1985, 1986), Jan et al. (1984) and Griffin (1972). Here the gradual loss of the anorthite component from plagioclase, as spinel then garnet became stable phases, went to completion and plagioclase was eliminated. resulting in assemblages such as gt-omph-phlog±opx in metadolerites and gt-diop-hbzoisite in pyroxenites (Mørk, 1985, 1986).

#### 6.3.1 PROBLEMS AND ASSUMPTIONS MADE IN CORONA-FORMING REACTIONS

In the literature there is only limited agreement on the basic assumptions required to both model and mass balance coronas. This was discussed in detail by Mongkoltip & Ashworth (1983). The olivineplagioclase corona has been the most extensively studied and basically comprises between two to five sequential layers separating olivine from plagioclase. They consist of the non-aluminous phase(s) opx, cpx or cummingtonite adjacent to olivine, while the aluminous phase(s) sp, gt, plag, hb, gedrite or a symplectite (plagioclase, spinel or garnet-bearing) are next to plagioclase. In most cases the contact between aluminous and non-aluminous phases does not represent the original ol-plag interface. Some common corona assemblages are listed in Table 6.3, which has been modified after Nishiyama (1983).

To begin with it is necessary to decide to what extent corona formation occurred in closed or open systems; i.e. components may have

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#### IABLE 5.3: Olivine corona sequences described in the literature

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REFERENCE	I REA	CTANTS	CORONA LAYER SEQUENCE	P.T CONDITIONS	ROCK TYPE AND LOCALITY
Emmett (1982)		An46-55	01/0px+0p/Amp/Plag 01/0px+0p/Gt_sym+Gt/Plag	P < 7 Kbars	Metadolerite; Jotun
Emelie (1983)	Fo40-76	An50-60 An30-40	01/0px/Amp+Sp/Amp/Plag 01/0px/Cox+Amp/Amp/Gt/Plag	Amphibolite facies	Ol-gabbros; Michael gabbros, Labrador, Canada
England (1974)	Fa44	Ån55	01/Ht/Cumm/Hb/Plag	Lower amphibolite facies	Metadolerite, Pottoyu Hills, Australia.
Esbensen (1978)	Fo42	An49	01 <u>+</u> Mt/Opx <u>+</u> Sp/Hb/P1ag	Amphibolite facies	Gabbro, Trondheim, Norway
Fredeson (1968)			01/0px <u>+</u> Iron ore/Hb <u>+</u> Sp/Plag	Amphibolite facies	Gabbro, Bamble, Norway
Gardner & Robine (1974)			01/0px/0px+Sp/Plag 01/0px/Cpx+Sp/Plag	Almandine-amphibolite facies	Gabbro, Seiland, Norway
Grieve & Gittins (1975)	Fo48-70	An62-68	01/0px/Hb+Sp/Plag (common)	T ~ 850°C	Ol-gabbro and troctolite, Hadlington Gabbro, Ontario.
Griffin (1971)			01/0ex/Cex/Hb/Gt+(Cex+Se)/Pl	Intermediate to high	Gabbros, ultramafics and
Griffin & Heier (1973)			01/0px/Cpx/Gt/Cox+So/Plag	pressure granulite (10-	dolerites; Norway
Griffin (1985)	Fo72-75	An38-42	01/±0px/Omph/Gt/Plag 01/+0px/Cpx/Pl/Gt/Plag	"11 Kbare; 900-950 °Cl. or eclogite facies	
Jan et al. (1984)			01/0px/Cpx/Hb+Sp/Plag	Pvy granulite facies	Troctolite: Chilae
			G1/Opx/Cpx+Sp/Gt (rare)	750-800°C: 5-7 kbars:	complex, Pakistan
			Opy/CoveGt/Plac	High-P grapulite	Jijal-Patan complex,
			ops/ops-oc/ling	T - 850 °C: 12-14 kbara	Pakiatan
Jaesten (1986a)	Fo64	An64	01/Opx/Opx+Sp/Parg+Sp/Plag 01/Opx/Parg/Parg+Sp/Plag	Amphibolite facies	Troctolite; Risör, Norway
Mason (1967)	Fo82	An67	01/0px/Hb/Hb+Sp/Plag		Troctolite, Sulitjelma. Norway
Miller (1974)	Fe79-85	An62-70	01/0p×/Gt/Sym/Plag 01/0p×/Cp×/Gt/Sym/Plag	550-700°C1 6-10 Kbars	Meta-peridotite Austroalpine Otzal nappe, Austria
Mongkeltip & Ashwarth (1983)	Fo80-82	An66-96	01/Opx/Amp/Amp+Sp/Plag	Amphibalite facies	Gabbres; Newer basic
Hurthy (1958)	Fo58-79		01/Opx/Amp+Sp+Gt/Plag	T = 550-600°C	Metadolerite; Mirzapur, India
Nishiyama (1983)	Fo62-64	An86-90	01/Cumm/Hb+Sp/Plag	Amphibolite facies	Metanorite; Mt. Ikoma. Japan
Otten (1984)	Fo45	An47	01/0px/Ged+Hb/Plag	500-550°C; P > 5 kbare	Ol-dolerite; Artfjället gabbra, Sweden
Reynalda & Frederickson (1962)	Fo65-72	An57-73	01/0px/Hb+Sp/Plag		Hyperites; south Norway
Rivers (1986)			01/Opx+Mt/Parg/P1	ag Amphibolite facies	Ol-gabbros; Grenvill
			01/0px+Mt/Cpx+Sp/Plag	-	Province, western Labrador
Sapountzis (1975)	Fo74-82	An90-95	Ol/Cox/Hb/Plag		Gabbro: Thessaloniki,
			01/0px/Cox/Hb/Plag		Greece
Starmer (1969)			01/0ox/Amo+So/Gt/Plag		
Van Lamuen (1979)	Fo38-55	An55	01/0px/Hb+Sp/Plag	Amphibolite-granulite facies	Ol-gabbros and iron ores; Finland
Whitney &	Fo54 (I)	An55 (1)	01/0px/Cpx+Sp/Plag (area I)	T = 700°C: 6-7 Kbars	Metagabbros; Adirondack
McLelland (1973)	Fo61-75	An30-40	01/0px+Cpx/Gt+Cpx/Plag (II) 01/0px/Cpx/Gt+Cpx/Plag (II)	T = 750-800°C; 7-8 Kbare	lowlands (area I) and highlands (area II)
Thie Study	Fo29-61	An29-41	01/Opx/Cox/Cox+Gt/+Gt/Plac	Amphibolite to granulite	Ol metagabbros from the
			01/0nv/Cov/Parc/ParceGt/Plac	factant 700-750 °C: 8-10 Kb	Central Gneles Belt, SW
			01/0ox/Cox/Para/CovaG+/P1-a		Grenville Province.
			01/Cau/CausGb/sGb/01aa		
			01/0px/0px+01/101/21ag		
			UI/UPX/LPX/Gt/Piag		
			UI/Cpx/Cpx+Spin/+Gt/Plag		
			G1/Opx+Gt/Moat/Gt/Plag		

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moved between olivine and plagioclase, but with the system effectively closed beyond their mutual interfaces. Alternatively, the system could have been completely open and the components transported over large distances. The most likely mechanism is a combination, in which the corona was essentially closed to certain ions of restricted mobility while other. more mobile cations exhibited open-system behaviour. This is certainly opaque oxide-plagioclase coronas where additional necessary for components, especially  $K_{2}^{0}$  and MgO, are required for the biotitehornblende-(garnet<u>+</u>cpx) reaction sequence. Furthermore, McLelland & Whitney (1983) suggested that olivine is required in the surrounding matrix as coronas around opaques are absent in olivine-free rocks. Thus, although individual coronas cannot be balanced for all elements, a chemical balance can be achieved on the scale of a thin section, so that large scale mass transfer does not appear to be necessary. However Austhreim and Robins (1981) proposed a large net influx of H<sub>2</sub>O to form hydrous cummingtonite-edenite + quartz coronas in anorthositic gabbro. This is in marked contrast to coronites in unretrogressed granulite facies metagabbros where the delicate corona structures must have formed under reduced water activity, because a free fluid would enhance reaction, deformation and recrystallisation.

The relative mobility of individual components is discussed in more detail in Chapter 7 where theoretical models, assuming steady-state diffusion, are developed for mass transfer. Kinetic reasoning in the literature advocates mobility of Mg and Fe whereas Na, Al, Ca and Si are regarded as less mobile, although the order of mobility varies between authors; Na, Ca are generally regarded as moderately mobile and there is agreement on the formation of opx from olivine by loss of Mg, Fe rather than addition of silica. These considerations have led to various attempts to mass balance the observed mineral compositions, using the assumption of an immobile element(s) and/or constant volume as a fixed frame of reference. Before balancing reactions it is necessary to recognise that the mineral composition of any solid solution phase only represents the reactant, if there has been no compositional adjustment of primary minerals during corona formation. As this is invariably the case, the initial reactant composition should be recalculated. This is attempted in Chapter 7 where, because of complementary reactions within matrix plagioclase, a "closed system" ratio of Na:Ca:Al:Si has to be adopted for "plagioclase" available at the outer corona interface.

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Various reaction mechanisms have been proposed for olivineplagioclase coronas and several authors (Whitney & McLelland, 1973,1983; McLelland & Whitney, 1980; Van Lamoen, 1979) invoked Fe-oxide as an additional reactant phase. Whitney & McLelland (1973) and Otten (1984) assume that Al,Si were immobile components in both ol-plag and opx-plag coronas. Mongkoltip & Ashworth (1983) proposed constant Al and constant volume replacement in olivine coronas. This requires a net gain of mobile oxygen in the form of  $H_{y}O$ ; i.e.

O1 + Plag +  $H_{0}$  +  $H^{+}$  Mg, Fe + Opx + Amph + Symplectite + Na + Ca

the symplectite consists of amphibole and spinel. In contrast van Lamoen
(1979) assumed Al was mobile and the corona closed to Si; i.e.
O1 + Plag + H<sub>2</sub>O + (Mg,Fe) → Opx + Hb + Sp + Na + Al.

- He proposed that Al liberated by reactions around olivine was then used for hornblende formation in adjacent opaque oxide coronas. In addition he proposed that magnetite-ulvospinel was probably the only reactant opaque oxide, as it alone can account for the Ti content of hornblende. A further point in support of simultaneous involvement of opaque oxides in ol-plag corona reactions is the similar composition of symplectites around both opaque oxides and olivine (Whitney & McLelland, 1973 and this study), implying simultaneous exchange between coronas.

## PART B

## 6.4 THE MINERALOGY OF THE CGB METAGABBROS

Microprobe analyses were obtained using both wavelength (WD) and energy dispersive (ED) methods. These techniques, together with calculated means and standard deviations for mineral analyses, are presented in Appendix III. In this Chapter predominantly WD analyses from both point and area sources, are plotted in the figures as they are more precise with a much lower standard deviation than ED analyses. In addition, each point commonly refers to the mean of up to ten WD analyses. A summary of the early coronite mineralogy is presented in Table 5.4, where all the recalculated mineral compositions were obtained by the methods discussed in Appendix IV.

#### 5.4.1 PRIMARY MINERALOGY

The primary gabbroic mineralogy comprised olivine-plagioclase-clinopyroxene-(magnetite-ulvospinel)+ilmenite-apatite+biotite+baddeleyite. However the chemistry of plagioclase and opaque oxides has been modified during corona growth. This section discusses likely primary mineral compositions.

#### **Olivine**

Olivine compositions vary from Fo<sub>29</sub> in 84DMSA-11F to Fo<sub>62</sub> in 85DMS-7. The range is more restricted within clusters (Table 6.4) and varies by up to 10-15 % Fo within individual gabbroic bodies. There is no compositional zoning within single olivine grains, but the composition can vary by a few mole % Fo within polished sections (notably 85DMSH-101C).

## Primary clinopyroxene

Clinopyroxene occurs either as an intercumulus phase between plagioclase laths, or in sub-ophitic intergrowths with plagioclase depending on modal proportions of primary minerals (section 6.4.3). occassionally partially enveloping olivine or opaque oxides. It is normally almost opaque in thin section due to very fine-grained dust which has been analysed as ilmenite in larger grains. This contributes 1-1.5 wt1 TiO, to broad-beam analyses (compared with D.3-0.4wt% in clear rims), and is assumed to represent ilmenite exsolution from an original titaniferous composition. If the excess Ti is removed with an amount of Fe corresponding to ilmenite, the resulting Mg number is approximately equivalent to secondary corona clinopyroxene. The ilmenite dust is progressively lost during the textural evolution when discrete ilmenite grains aggregated within pyroxene. Titanium must also diffuse out into the matrix and may be taken up in retrogressive amphibole at the margins of mafic phases.

The recalculated pyroxene compositions are represented in Table 6.4. The site occupancies, obtained from a range of samples throughout the evolutionary seqence, are given in Figure 6.8a and show a strong positive correlation between Na and Al(oct). However no correlation exists between the Ti content and other cations in the octahedral site and suggests that some compositional adjustment of the original titaniferous composition has occurred.

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PHASE	OPEONGO	850MSH-101	DORSET	85DMSH-4	HUNTSVILLE	GO HOME	KIOSK	ROSSEAU
OLIV	Fo29-41	Fo34-45	Fo46-47	Fo42-56	Fo43-60	Fo51-62	Fo50-59	Fo55-59
PRIM CPX	Wo42-5En35-9 F#16-23	Wo45-7En37-40 Fs14-8	Wo45En42Fs13	Wo46-7En39-42 Fs12-4	Wo46-8En40-4 Fs8-14	Wo44-5En41-44 Fs10-12	Wo47En41-3 Fs10-12	Wo46En41Fs13
PLAG	An38-42	An31	An42	An33-39	An34-40	An38-42	An25-40	An30-37/23-30
MOAT	An24-29	-	An32-38	An24-25	An20-33	-	-	An32-34 (R-22)
SPIN	Spin17-28	-	Spin35	Spin35-6	Spin49-53	-	Spin30-8 (Op)	-
COR OPX	En48-58 Fs42-52	En51-9 Fs41-49	-	En58-67 Fs33-42	En66-68 Fs32-34	En63-70 Fs30-37	En61F\$39	En60-69 Fs31-40
COR CPX	Wo45En36-9 F≋16-9 + 6-8% Jd	Wo44-6En36-42 Fs11-20 + 12% Jd	₩o45En45Fs13 ' + 6% Jd	Wo46-7En41-4 Fs10-12 + 11% Jd	Wo46En41-4 F\$10-13 + 9-13% Jd	Wo46En41-5 F\$9-14 + 6-9% Jd	Wo46-7En42-4 F\$9-10 + 12-19% Jd	Wo47-8En42-4 F\$8-10 + 10% Jd
PALE AMP		Ferroan parg				Ferroan parg	Ferroan parg	
GNT	And1-3Py18-25 Sp2-3Gr14-18 Alm57-60	And0-3Py17-24 Sp2Gr15-27 A1m53-59	And1Pyr26-8 Sp2Gr13-14 A1m52-53	And2-6Py24-9 Sp1-2Gr12-16 A1m52-56	And1-3Py26-34 Sp1-3Gr13-15 A1m49-55	AndO-2Py25-34 Sp1-2Gr16-18 Alm47-56	And3-8Py22-8 Sp2Gr12-22 A1m46-52	And3Py30-32 Sp1Gr15-16 A1m49-50
Ti-AMP	K-Kaersutite or Ti,K,Fer Pargasite	Ti,K,Ferroan Pargasite -	Ti,K,Ferroan Pargasite	Ti,K,Ferroan Pargasite	Ti,K,Ferroan Pargasite	Ti,K,Ferroan Pargasite	Ti,K,Ferroan Pargasite	Ti,(K),Ferroan Pargasite

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TABLE 5.4: A summary of average mineral compositions for various metagabbroic clusters.

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#### Plagioclase

During corona growth primary calcic plagioclase became unstable with olivine and opaque oxide and liberated calcium to corona formation. This left excess Al which, coupled with a complementary flux of (Mg,Fe) from olivine, resulted in the exsolution of very fine-grained spinel "dust". There is a good positive correlation between the Fo content of olivine and the Mg number of spinel clouded plagioclase (Fig. 6.3). The spinel inclusions commonly contribute 3-4 Wt 1 (Fe,Mg) to area scans of samples from Stage I; in 85DMSK-10 spinel contributes up to 8 Wt% (Mg,Fe). This is equivalent to 0.24-0.36 moles spinel (based on 4 oxygens), or 0.7 in DMSK-10, per mole of plagioclase (based on 32 oxygens), and 2.4-3.5(7) % by volume. The results of 50x50 µm area scans are presented in Figure 6.4a to d. In the least-evolved samples, the integrated Al:Si is consistently around 0.61. This constant ratio prevails despite the variable depletion in calcium (Al:Ca in Fig. 6.4) and suggests that Al, Si had restricted mobility. Provided this was then case, the Al:Si ratio reflects a primary plagioclase composition of  $An_{5n-55}$ . The importance of this is discussed further in Chapter 7, section 7.3. It is supported by the normative An/(An+Ab) ratios (Chapter 4, Fig. 4.1a) and the recalculated plagioclase compositions from petrological mixing models of the whole rock analyses (Table 6.6, section 6.4.3), although the latter technique produces more sodic compositions for the Fe-rich samples.





In the CGB, the proposed primary plagioclase composition is analogous to the calcic plagioclase reported in the Adirondacks (section 6.2.1). However the present anorthite content varies from  $An_{29-42}$ , although this is restricted to a few mol% An within individual clusters (Table 6.4). In the most sodic sample, 85DMSK-10, there is a zonal arrangement of spinel

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clouding adjacent to the garnet symplectite (Plate 6.1c) whereas in other samples, the symplectite layer commonly cuts across the spinel-clouding (Plate 6.1a & b). This provides evidence for spinel clouding both pre- and syn- garnet symplectite formation. The Ca flux appears to be have been operative from the earliest stages of corona formation, possibly initiated as the gabbros passed through the spinel stability field. It continued until all the spinel-clouded plagioclase adopted a constant composition and/or the reactions stopped; plagioclase adjacent to coronas developing clouding which in most cases, was subsequently overgrown by the continued growth of the symplectite, when Ca was supplied from more distant plagioclase.

In the Go Home and Opeongo bodies, the composition of spinel-clouded plagioclase is remarkably constant, at around  $An_{18-42}$  (Table 6.4). This is consistent with results obtained by Whitney & McLelland (1973) and McLelland & Whitney (1980) for similar garnet-bearing coronite metagabbros in the Adirondacks, New York State. In both areas the clouding in the cores clearly mimics original zoning in plagioclase, whereas clear lath margins are more sodic than  $An_{3R}$  and probably too sodic to participate in corona-forming reactions. Thus the minimum An content for spinel-clouding may represent the most calcic, stable plagioclase composition in local equilibrium with the corona phases and is used for geobarometry in section 6.8. In the Seguin, Kiosk and Rosseau clusters, the An content is lower and commonly more variable, both within individual bodies and within each cluster. There are a number of explanations for this: in the more evolved samples such as 85DMSK-2, 85DM-230, 85DMSR-30 and 85DMSH-101C, the annealing of spinel dust and continued loss of calcium that accompanied greater garnet development, has variably reduced both the An content and the Al:Si ratio (Fig. 6.4a-d). In addition some of these samples also appear to have had more sodic primary compositions (Table 6.6).

In unevolved samples, such as 85DMSR-82.28 and 85DMSK-10, the integrated spinel-clouded plagioclase has retained the "magmatic" Al:Si ratio, but has adopted more sodic compositions. Here the An content was apparently controlled by the initial corona-forming reactions and unlike the evolved samples, has not been modified by subsequent metamorphic reworking. In 85DMSK-10 the zonal arrangement of spinel inclusion around coronas is responsible for the large compositional variation of  $An_{26-33}$ ; the cores of plagioclase laths being *LESS* calcic than intensely clouded plagioclase immediately adjacent to the coronas. Here it appears that

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calcium was continually supplied from matrix plagioclase to the corona interface, progressively resulting in very intense spinel-clouding at the outer edge of the corona, while matrix plagioclase developed relatively constant levels of Ca-depletion. This represents a disequilibrium compositional variation at the corona interface where reactions were "frozen" at variable levels of Ca-depletion. In samples 85DMSR-82 and 85DMSR-28, the calcium flux continued until all the plagioclase adopted approximately constant compositions, at An  $_{30-32}$  and An  $_{32-37}$  respectively, with no zonal arrangement of spinel-clouding. The absolute An content in the least-reacted coronites may be controlled by the pressure of corona formation and hence the level of intrusion and subsequent cooling history. This is further complicated by the possible onset of crustal thickening during static cooling and is discussed further in section 6.8.

## Ilmenite-(magnetite-ulvospinel)

Primary (Nt-Usp) grains have been retained in some of the coarsegrained Opeongo samples. These have been analysed and charge-balanced for  $Fe^{3+}$  following Carmichael (1967) and recalculated into end-members after Powell & Powell (1977). Ulvospinel contributes between 3 and 19 mol% to magnetite analyses from TiO<sub>2</sub> contents of 1.5 to 7 Wt%. Chrome is generally low (0.4-0.6 Wt%), although magnetite with up to 5 Wt%  $Cr_2O_3$  as chrome spinel has been analysed. The alumina content varies from 0.7-8.1 Wt% and MgO from 0.3-0.7 Wt%. The magnetite grains contain lamellae of ilmenite (Plate 6.8b) which is also present as discrete grains intergrown with Mt-Usp, the latter probably forming predominantly from the transformation of magnetite during corona growth. Ilmenite analyses include MnO (0.2-0.3 Wt%), MgO (0.7-1.09 Wt%) and  $Cr_2O_3$  (0.04-0.15 Wt%). In addition to Fe.Ti-oxides, some samples also contain sporadic iron sulphides which implies reduced oxygen fugacity during magmatic crystallisation.

#### Accessories: biotite, apatite and baddeleyite

The occurrence of baddeleyite was mentioned in section 6.1. Apatite and biotite occur as interstitial grains and apatite is commonly included in the rims of primary clinopyroxene and plagioclase laths.

Primary biotite is similar to corona biotite, but tends to be more Fe-rich. The biotite analyses have not been recalculated to give  $Fe^{3+}$ , but site occupancies have been determined directly from WD microprobe data. In the "ideal biotite plane" (Figure 6.5a; Guidotti, 1982) the biotites lie close to the annite-phlogopite join and tend towards and overlap the



phlogopite boundary (based on an Mg:Fe of 2:1). In this Figure any composition can be modelled by a combination of Tschermaks  $(Al^{VI}Al \ ^VSi_{-1}Mg_{-1})$  and FeMg\_1 exchange from the phlogopite end-member. The main deviation from this simplified composition plane is from high Ti-contents and this is represented in Figure 6.5b-d. High Ti is typical of biotites from high grade granulite terranes (Guidotti, 1982) where Ti substitutes into octahedral sites. This is balanced by vacancies (Figs. 6.5d) involving:

 $2(R^{2+})^{v_1} = (Ti^{4+})^{v_1} + ()^{v_1}$  and  $2(A1^{3+})^{v_1} = (Ti^{4+})^{v_1} + R^{2+}$ . - where () represents a vacancy. Furthermore, the poor positive correlation of Ti with Fe2 and good negative correlations with Mg or Mg number, suggest the substitution of Ti is correlated with FeMg, exchange.

## 5.4.2 CORONA MINERALOGY - Samples containing a (gt-cpx) symplectite.

Corona pyroxene and garnet show good evidence of equilibrium partitioning between Fe and Mg (Fig. 6.6c & d) which implies local equilibrium across layer boundaries. The equilibrium constant ( $K_D$ ) for opx-cpx pairs is approximately 1.56, while  $K_D$  for gt-cpx is ~5.83, although several Fe-rich compositions lie off this line. The Mg number of corona phases increases from olivine to clinopyroxene and decreases towards garnet and spinel-clouded plagioclase (Fig. 6.6b). Coexisting garnet, clinopyroxene and orthopyroxene assemblages are plotted in Figure 6.7a. Again there is a systematic relationship, but note that the mean of garnet analyses from the Kiosk cluster are considerably more calcic.

#### Corona orthopyroxene

Orthopyroxene has a radial orientation around the olivine core and fairly constant composition across the layer. The main variation within any one sample is in wt7  $Al_2O_3$  which varies by up to 0.5 Wt7 across the layer, with less aluminous compositions adjacent to olivine. Alumina contents throughout the CGB clusters vary from 0.8 to 2.05 Wt7. The mean Al contents of co-existing corona orthopyroxene and clinopyroxene pairs are shown in Figure 6.8b. There is a broad correlation of decreasing Al(IV) with increasing Al(VI) for both pyroxenes, especially clinopyroxene. Furthermore, orthopyroxene from olivine coronas with a pargasitic layer (---) are more depleted in alumina. Calcium contents are very low resulting in simplified binary compositions of  $En_{48}Fs_2$  to FIGURE 6.6: Coexisting Mg Nos. and Fe/Mg ratios for corona phases: a - mean Mg No. of coexisting ol-opx and opx-cpx where (----) represents the theoretical ol-opx partitioning at 900 C after Medaris (1959), and (---) represents opx-cpx partitioning in granulites from Loomis(1977).







FIGURE 5.7a: Mean Ca-Mg-Fe(T) for coexisting opx-cpx-gt in coronites.

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FIGURE 6.7b: Recalculated clinopyroxene end-members from mean compositions.



FIGURE 6.8: Pyroxene site occupancies from recalculated WD analyses of corona (a & b) and primary clinopyroxene (a only).



# En<sub>70</sub>Fs<sub>30</sub> (Table 6.4).

#### Corona clinopyroxene

This has zero or minimal TiO<sub>2</sub> (< 0.1 wt%). Again the main variation within a layer is in Wt% Al<sub>2</sub>O<sub>3</sub> which ranges by approximately 1.5 Wt%, being less aluminous adjacent to orthopyroxene. The average alumina contents throughout the metagabbroic clusters ranges from 3 to 4.24 Wt% and are greatest in 85DMSK-10. The site occupancies for Al(VI), Al(IV) and Na are shown in Figure 6.8 and there is a positive correlation between increasing Na and Al(VI) (Fig. 6.8a). When recalculated into end-members this represents an increase in jadeite with negligible Ca-Tschermaks (Fig. 6.7b). In terms of recalculated quadrilateral components, the average clinopyroxenes range from Wo<sub>40</sub> En<sub>35</sub> Fs<sub>19</sub> to Wo<sub>46</sub> En<sub>45</sub> Fs<sub>9</sub>.

#### Ti-poor amphibole

This is present in olivine coronas from sample 84DMS-13A and less commonly in 85DMSK-2, 85DMSH-101C and 85DMS-6. It is pale green and has a variable composition, especially in Wt1 Al $_{2}O_{3}$  and SiO $_{2}$  which vary by  $\pm$  2 Wt%. The amphibole is consistently a pargasite (Leake, 1978). Recalculated site occupancies (referred to as ol-pargasites) contrast with brown, titaniferous amphiboles (Ti-pargasites) from the opaque oxide coronas in Figure 5.9a-f. The latter vary from a titanian <u>+</u> potassian ferroan pargasite to kaersutite (Table 6.4). The ol-pargasites have a restricted range of Al(VI) and do not exhibit Tschermaks (Ts) substitution  $(R^{2+}, Si^{++})$ = Al(VI),Al(IV)) which is responsible for the trend in Ti-pargasites (Fig. 6.9b). In Figure 6.9c both amphibole compositions define two separate trends of increasing Ti with decreasing Al in the octahedral sites. This simply reflects an increase in the Kaersutite component where Ti substitutes for Al(VI). Ol-pargasites are more magnesian than corresponding Ti-pargasites (Figs 6.9d,e) and the high Ti and low A1(VI) content correlates with high Fe/Mg ratios. Thus, as in biotite, the substitution of Ti for Al(VI) is accompanied by FeMg\_, whereas increasing Al(VI) by Ts exchange involves an increase in Mg by the MgFe\_, exchange vector.

The Na content of the M4(8) site is plotted against total calcium in Figure 6.9f and two distinct trends are apparent: The ol-pargasites define a gradient of  $\infty$ -0.5 which suggests a coupled replacement for Ca in the M4 site. In addition only the ol-pargasites show any Fe2 in the M4-site (a cummingtonite component) and there is a negative correlation between (Fe2)M4 with increasing Si. As a result, a coupled substitution of Fe and

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FIGURE 6.9: Site occupancies recalculated from WD analyses of Ti-poor pargasites from olivine coronas (DMS-6, DMS-13A, DMSH-101C, DMSK-2), and Ti-rich pargasites from both opaque coronas and from around primary clinopyroxene (RETR).



Na replaced Ca in the M4 site. In the Ti-pargasites the gradient is -1.0 which represents an approximate 1:1 replacement of Ca by Na in M4 and represents the action of the plagioclase exchange component; i.e. NaSi(AlCa)\_1.

#### Bulk symplectite

The symplectite consists of a fine-grained granular or lamellar intergrowth of two minerals and (gt-cpx) is the dominant type. It is present as an outer layer on both the olivine and opaque oxide coronas. There is very little difference in composition between the two coronas, which again suggests equilibration on the scale of a polished section although the opaque symplectites typically have slightly lower Mg numbers. Analyses have also been obtained from the (amph-gt) symplectites in 840MS-13A and the rare spinel-bearing symplectite in 850MSK-10; the bulk composition of the former is similar to the cpx-bearing example, apart from the higher content of alkalis. No uncontaminated analyses have been obtained for the other mineral in the spinel-bearing symplectite but based on the calcium content of area scans, it appears to be clinopyroxene.

The bulk symplectite compositions were obtained by WD analyses on a 50x50 µm area. Compositions vary depending on (1) whether they were taken adjacent to the outer rim of discontinuous garnet, when the contribution of Clinopyroxene or amphibole (84DMS-13A) is reduced, or (2) whether they were adjacent to monomineralic clinopyroxene or amphibole, where the opposite effect is observed. The proportion of garnet relative to cpx or amphibole has been calculated for the average, central and most cpx-rich bulk compositions using a least-squares approximation program. Weighting was achieved using a variance matrix, where diagonal elements represent the square of the standard deviation for each element in the bulk symplectite scans (Spear et al., 1982). This weights the minor elements and results in a better fit to the data. The results are presented in terms of the mole fraction garnet  $(X \xrightarrow{Sym})$  in Table 6.5; the most cpx-rich compositions come from 85DMSR-82, 85DMSK-10 and notably 84DMS-19. The latter as mentioned earlier, has lost olivine but still has a high degree Of lamellar symplectite development, reflecting diffusion-controlled growth. However, in most cases, the results range from 0.7 to 0.8 although evolved samples with greater garnet development, have lower proportions of clinopyroxene in the symplectite (eg 85DMSK-2 and 85DMSH-101C). In 84DMS-13a, because the Al,Si content of amphibole and garnet are relatively similar compared with gt, cpx, X is markedly affected by

small changes in the symplectite composition and the variable Al,Si content of the pargasite. There is also the possibility that minor amounts of clinopyroxene are present in the symplectite. A compromise of X = aaph 0.2 is obtained for the mean and spatially central compositions. The minimum proportions of garnet immediately adjacent to the clinopyroxene or amphibole layer, range from 0.41 to 0.67. The majority of (gt-cpx) symplectites lie between 0.5 and 0.6 and this is compatible with average compositions of 0.7-0.8; i.e. spatially and compositionally half way between pure and minimum proportions of garnet in the symplectite.

**TABLE 6.5:** Mean, spatially central and maximum proportions of clinopyroxene in the symplectite. Samples arranged in order of increasing corona development.

SAMPLE	MEAN	CENTRAL	MAX CPX(adj	to cpx)
85DMSR-82	0.56	0.57	0.43	
850MSK-10	0.65	0.70	0.54	
84DMS-13A	0.85	0.75	0.67	
85DMS-8	0.76	0.82	0.52	
85DMSR-28	0.74	0.80	0.56	
86DMS-18	0.68	0.72	0.61	
85DMS-7	0.80	0.81	0.64	
85DMS-6	0.71	0.64	0.59	
85DMSR-30	0.75	0.88	0.52	
85DMSK-2	0.86	0.86	0.50	
84DMS-19A	0.61	0.61	0.41	
850MSH-101C	0.81	0.84	0.55	
85DMSA-8B	0.76	0.71	0.50	
85DM-230	0.77	0.83	0.67	

Various ratios from symplectite analyses are presented in Figure 6.4a-d. The average symplectite has an Al:Si ratio of around 0.55 although there are important departures from this. In particular 85DMSK-10 and 85DMSR-82 plot at considerably lower Al:Si (consistent with their higher calcium content, see below). In addition the Al/Si ratio in 85DMSR-82 (Fig. 6.4c) is approximately the same as pargasitic amphibole (Fig. 6.4a), but is less calcic (i.e. higher Al/Ca). If Al, Si had restricted mobility, but with Si more mobile than Al (see Chapter 7), it may be that pargasite layers form metastably to accommodate a high calcium flux compared to (gt-cpx) symplectite in other corona sequences. In effect, this represents insufficient Al at the reaction site to accommodate the calcium liberated from plagioclase, as a garnet-bearing symplectite and may also explain why symplectite form as the Ca/Al content is similarly high (Fig. \$pinel 6.4d). This hypothesis is further supported by the presence of only calcic phases in the spinel-bearing coronas; i.e. clinopyroxene occurs adjacent to olivine and there is no orthopyroxene layer. Furthermore, the spinel-bearing coronas are typically located around olivine adjacent to, or partly enclosed by primary clinopyroxene, suggesting that the latter may have supplied additional calcium and/or acted as a template for growth. Moreover, the Mg number of the spinel-bearing symplectite is considerably higher than that of olivine which implies that: (1) considerably more Mg left the olivine core, or (2) primary clinopyroxene was involved. As the olivine composition is indistinguishable from olivine in garnet-bearing coronas, the former is more plausible as it is unlikely that both olivines fortuitously underwent similar amounts of Mg-depletion.

In Figure 6.10a & b the range and mean mole-fraction of calcium  $(X_{r_{i}})$ in both the symplectite and garnet are plotted against the An content of spinel-clouded plagioclase. In the least evolved samples there is a broadly consistent relationship between higher  $X_{Ca}^{aym}$  and greater depletion in anorthite, though the trend is masked to some extent by the broad range of analyses obtained across the symplectite layers. Nonetheless, both mean and minimum garnet contents in the symplectite (i.e. min  $X_{r_a}$ ) define negative trends with decreasing anorthite; i.e. Ca-rich symplectites in 85DMSR-82 and 85DMSK-10 are associated with the most sodic plagioclase (Fig. 6.10a) which still retains an approximately primary Al:Si ratio (Fig. 6.4c & d). Thus it appears that these symplectites are the direct result of greater Ca-supply from plagioclase, the spinel-symplectite in forming metastably with respect to a clinopyroxene-rich. 85DMSK-10 garnet-bearing symplectite. The more evolved samples exhibit fairly constant calcium contents, comparable to the Go Home samples, but at lower anorthite. Here, metamorphic reworking has increased the proportion of garnet in the symplectite (decreasing  $X_{r_{a}}^{sym}$ ) for a given plagioclase composition.

Another interesting feature of Figure 6.4 is that the Al:Si in spinel-clouded plagioclase gradually decreases in the more evolved samples (Fig. 6.4b and DMSR-30 (6.4c), DMSK-2,(6.4d)) and converges with the mean Al:Si in the corresponding symplectite. Thus plagioclase may have a minimum Al:Si capable of supporting a symplectite; beyond this composition further annealing and loss of spinel being coeval with unmixing of the symplectite into garnet and clinpyroxene. FIGURE 6.10: The variation in mole fraction Ca for garnet (a) and symplectite (b) versus the range in An-content of spinel-clouded plagioclase ( corresponds to more evolved samples).



#### Garnet

Narrow, discontinuous garnet rims are commonly present adjacent to heavily spinel-clouded plagioclase in the least-reacted coronites. Garnet has a fairly constant composition within a polished section, but varies throughout the CGB in terms of Fe/Mg (Fig. 6.7a), depending on the olivine composition. Recalculated average analyses, converted into end-members, range from  $\operatorname{And}_{1}\operatorname{Py}_{18}\operatorname{Sp}_{1}\operatorname{Gr}_{16}\operatorname{Alm}_{50}$  to  $\operatorname{And}_{1}\operatorname{Py}_{34}\operatorname{Sp}_{1}\operatorname{Gr}_{17}\operatorname{Alm}_{47}$  (Table 6.4) with remarkably little variation in grossular; the only exception is in Kiosk domain where the Ca contents are higher, resulting in up to 227 grossular (Figs. 6.7a & 6.11).

The evolved coronites (85DMSK-2, 85DM230, 85DMSR-30 and 85DMSH-101C) exhibit extensive monomineralic garnet development at the expense of both plagioclase and the symplectite layers, depleting the latter in calcium. Subhedral garnet shows progressive and variable enrichment in grossular (Fig. 6.11), with outer garnet being most enriched. This resulted in a large range for  $\chi_{Ca}^{Gt}$  (Fig. 6.10a) and the high standard deviations reported in Appendix III.





#### Spinel

Individual analyses were obtained using the Camebax microprobe at the University of Keil (FDR) where a finer beam was possible. These are represented by  $\Delta s$  in Figure 6.3 and are broadly consistent with the
positive trend between olivine composition and the Mg number of spinelclouded plagioclase. The spinels are almost pure spinel-hercynite solid solutions with minor amounts of MnO (up to 0.22 Wt%), ZnO (0.7-1.06 Wt%) and CrO<sub>2</sub> (0-0.05 Wt%).

#### Opaque corona phases

The compositions of corona and primary biotites (Fig. 6.5) are discussed in section 6.4.1, while Ti-amphiboles from opaque coronas are compared with Ti-poor pargasites in Figure 6.9. There are notable differences between the two and the Ti-amphiboles range from a titanian ferroan pargasite to kaersutite (Table 6.4). Coexisting biotites and amphiboles in opaque oxide coronas have a much more restricted range Mg number than the corresponding mafic phases in olivine coronas, and amphibole is slightly less magnesian than co-existing biotite. Retrogressive amphibole is similar to amphiboles around opaque-oxides (Fig. 6.9 & 6.13) and is discussed in section 6.4.4.

### 6.4.3 MODAL PROPORTIONS AND MASS BALANCE ESTIMATES FOR STAGE I

Estimated modal proportions for samples from Stage I and early Stage II were obtained by both point-counting thin sections and from direct measurements of layer widths around olivine and opaque oxide coronas.

#### **POINT-COUNTING**

Table 6.6a,b presents results from up to 1100 point counts in the medium-grained, least-reacted metagabbros. Mafic minerals range in size from 1-3 mm while plagioclase laths reach 8mm in length and it is likely that one thin section will not give a true cross-section of the bulk-rock and this is tested here. In coarse-grained samples point counts are meaningless for the available area to be counted although in qualitative terms, the Opeongo samples are macroscopically richer in primary clinopyroxene which reaches several centimetres in size and is sub-ophitic, rather than interstitial to plagioclase laths. Many samples display a plagioclase lamination and point-count traverses were approximately perpendicular to this. As discussed in chapter 4, the liquid evolution within each cluster of gabbroic rocks was probably accomplished by plagioclase and lesser amounts of olivine fractionation. Thus primary modal proportions, recalculated by extracting the reaction products, will not represent a quenched liquidus mineralogy. However finer grained

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samples collected from near the margins of several bodies may provide a closer approximation to the parental composition. These correspond to samples 85DMSR-28, 85DMS-6 and 85DMSD-68 in Table 6.6a.

The recalculation of point-count results into primary proportions Isecond column in Table 6.6a) requires the following simplifying assumptions: a) overall constant volume replacement; b) the corona opx and cpx formed solely at the expense of olivine; c) the pargasite, symplectite and garnet layers replaced plagioclase; d) biotite replaced opaque oxide and furthermore as noted by Van Lamoen (1979), Ti-rich magnetite with ilmenite lamellae is capable of supplying the necessary titanium. As a result it is assumed that biotite formed at the expense of titanomagnetite, while ilmenite behaved passively or was a product of the reaction. To test these assumptions, the corresponding whole rock compositions have been run through a petrological mixing program (Bryan et **al.**, 1969). using microprobe analyses of the primary mineralogy. Here Several coarse grained samples were also recalculated into modal proportions. The results are shown under "PETMIX" in Table 6.6a. There is reasonable agreement with recalculated point counts, although the assumptions tend to underestimate primary olivine and clinopyroxene proportions in favour of plagioclase. The discrepancy for clinopyroxene is not an artefact of the mixing program because the "PETMIX" proportions, with the exception of the coarse-grained Fe-rich cumulate (850MSA-11D), are remarkably consistent (10-13% cpx), and is probably the result of Unrepresentative point counts. This can be explained by the observed variation in clinopyroxene proportions throughout individual gabbroic bodies where it is present as a late interstitial or sub-ophitic phase, and thus became concentrated in patches. As a result one thin section may not represent a true sample of the bulk rock.

To further test the accuracy of point counts, the modal proportions were recalculated into cation percentages both before and after corona growth (Table 6.6b), using the molar volume data in Robie et al. (1979), and compared with whole rock cation proportions from XRF results. There is a reasonable correspondence between point count estimates and the whole rock, but Mg is low and Al high in the recalculated reactant compositions, suggesting olivine proportions have indeed been underestimated by the assumptions in the recalculation of point counts. It is possible that olivine compositions became more Fe-rich during corona growth, volume diffusion within olivine being rapid enough to eliminate any compositional

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<u><b>IABLE 6.6a</b></u> : Estimated volume	proportions in the who	lerock (N/A = not analysed	i; N/I = not included in	n "petmix").
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AMPLE	850MSK-10			850MSR-82	?		840MS-134			85DMSR-26	)	
	POINT	PRIMAR	PROPS.	POINT	PRIMARY	PROPS.	POINT	PRIMAR	PROPS.	POINT	PRIMARY	PROPS.
	COUNT (2)	RECAL	PETMIX	COUNT(2)	RECAL	PETMIX	COUNT (Z)	RECAL	PETMIX	COUNT (%)	RECAL	PETMIX
	7.7	17.3	23.7	9,4	18.7	23.2	7.3	18.6	19.2	2.2	14.7	19.2
PX	1.9	-	-	5.0	-	-	7.8	-	-	7.2	-	-
X	7.7	-	-	4.3	-	-	3.5	-	-	5.3	-	-
:PX	9.3	9.3	10.1	8.9	8.9	11.0	0.7	0.7	7.1	5.0	5.0	10.7
I-SYM	23.0	-	-	15.1	-	-	6.1	-	-	17.5	-	-
7	2.7	-	-	2.5	-	-	4.9	•	-	5.8	-	-
-SYM	0.9	-	-	0.2	-	-	-	-	-	-	-	-
RG	-	-	-	-	-	-	7.8	-	-	-	-	-
-PL	40.1	-	-	46.0	-	-	41.9	-	-	45.9	-	-
PL.	-	66.7	61.1	-	66.4	60.4	-	71.9	68.7	-	71.9	64.2
-AHP	- '	-	-	2.6	-	-	11.2	-	-	2.7	-	-
н	1.6	1.67	2.1	1.5	1.57	1.5	3.1	3.17	1.7	2.6	2.67	Z.2
-USP	-	4.47	2.9	-	3.67	3.9	-	4.27	3.3	-	4.9?	3.6
	4.4	.44.4	N/1	3.6	(3.6	N/1	4.2	<4.2	N/I	4.9	<4.9	N/1
, 	0.7	0.7 •	N/1	0.5	0.5	N/I	1.3	1.3	N/I	0.9	0.9	N/I
INTS	751			860			1130		<i></i> _ <i></i>	1000	*****	
/AN+A8	t		An52			An50			An51			An52

SAMPLE	85DMS-8			860MS-18			85DMS-7			85DMS-6		
	POINT	PRIMAR	Y PROPS.	POINT	PRIMARY	Y PROPS.	POINT	PRIMARY	PROPS.	PGINT	PRIMAR	Y PAOPS.
	COUNT(2)	RECAL	PETHIX	COUNT (Z)	RECAL	PETHIX	COUNT (2)	RECAL	PETMIX	COUNT(Z)	RECAL	PETMIX
OL	3.6	15.1	18.2	4.9	16.7	N/A	6.7	17.9	23.7	1.7	17.5	17.6
OPX	7.2	-	-	8.8	-	-	6.8	-	-	9.0	-	-
CPX	5.5	-	-	3.0	-	-	4.4	-	-	6.8	-	-
PCPX	7.2	7.2	11.3	1.1	1.1	N/A	8.9	8.9	10.0	7.1	7.1	10.2
GT-SYN	14.9	-	-	10.8	-	-	8.5	-	-	9.4	-	-
GT	2.8	-	-	4.4	-	-	6.0	-	•	6.9	-	-
SP-SYM	0.5 .	-	-	-	-	-	0.9	-	-	0.4	-	-
PARG	-	-	-	-	-	-	-		-	1.0	-	-
SP-PL	46.3	-	-	57.9	-	-	45.3	-	-	44.6	-	-
թ-ԲԼ	-	70.4	65.2	-	75.8	N/A	-	69.2	61.0	-	69.0	67.5
TI-AMP	5.9	-	-	2.7	-	-	8.5	-	-	6.7	-	-
ILM	1.1	1.17	0.6	0.7	0.77	N/A	0.9	0.97	0.4	2.1	2.17	1.1
MT-USP		4.47	4.6	-	5.17	N/A	•	2.47	5.1	-	3.57	3.6
61	5.5	<5.5	N/I	5.1	<5.1	N/I	2.4	<2.4	N/I	3.5	<3.5	N/1
AP	0.1	0.1	N/I	0.1	0.1	N/I	-	-	N/I	0.2	0.2	N/1
POINTS	1090			929			945		*******	759		
AN/AN+A8	h.		An52			N/A			An54			An52

SAMPLE	850MSR-30	)		850MSK-2			850MSR-33	3		84DMS-19/	1	
	POINT	PRIMARY	PROPS.	POINT	PRIMARY	PROPS.	POINT	PRIMARY	PROPS.	PDINT	PRIMAR	Y PROPS.
	COUNT (%)	RECAL	PETMIX	COUNT (Z)	RECAL	PETMIX	COUNT (2)	RECAL	PETMIX	COUNT (2)	RECAL	PETMIX
0L	5.6	13.5	17.1	N/A	N/A	17.5	0.0	11.8	N/A	0.0	11.9	N/A
OPX	0.3	-		N/A	-	-	5.6	-	-	8.9	-	-
CPX	7.6	-	-	N/A	-	-	6.2	-	-	3.0	-	-
PCPX	4.9	4.9	10.6	N/A	N/A	10.1	9.0	9.0	N/A	1.7	1.7	N/A
GT-SYH	14.7	-	-	N/A	-	•	15.0	-	-	10.5	-	-
GT	3.Z	-	-	N/A	-	-	7.4	-	-	8.1	-	-
SP-SYN	-	-	-	N/A	-	-	-	-	-	-	-	-
PARG	-	-	-	N/A	-	-	D. 1	-	-	-	-	-
SP-PL	51.3	-	-	N/A	-	-	43.1	-	-	49.8	•	-
P-PL	-	70.8	64.8	-	-	62.5	-	69.1	N/A	-	77.3	N/A
TI-AHP	1.6	-	-	N/A	-		3.5	•	-	8.9	.=	-
ILH	3.1	3.17	2.9	N/A	-	4.4	4.1	4.17	N/A	2.5	2.57	N/A
MT-USP	-	6.87	4.5	N/A	-	5.5	-	5.17	N/A	-	8,97	H/A
81	6.8	<6.8	N/I	N/A	-	N/1	5.1	<5.1	N/A	5.9	<5,9	N/A
AP	0.2	0.2	N/I	N/A	N/A	N/1	0.3	0.3	N/A	0.1	0.1	N/A
POINTS	1037	ی دو دو دود داد دن دو دو <del>در</del> به <del>م</del>	4679222444	N/A			828			1004		
AN/AN+AB	1		An48			An48			N/A			N/A

#### IABLE 6.6a (cont'd)

SAMPLE	850HSK-6			850MSH-40	3		850MSH101	C		BSDMSK-9/	•	
	POINT COUNT(2)	PRIMARY Recal	PROPS. PETMIX	POINT COUNT(2)	PRIMARY RECAL	PROPS. PETNIX	POINT COUNT(X)	PRIMARY RECAL	PROPS. PETMIX	POINT COUNT(2)	PRIMARY RECAL	PROPS. PETMIX
0L	0.0	7.0	N/A	2.8	16.0	19.6	 N/A		14.9	1.0	7.4	
OPX	2.7	-	-	8.6	-	-	N/A	-	-	1.0	-	-
CPX	- 4.3	-	-	4.6	-	-	N/A	-	-	5.4	-	-
PCPX	16.4	16.4	N/A	7.7	7.7	14.3	N/A	-	16.0	13,3	13.3	H/A
GT-SYM	8.1	-	-	15.0	-	-	N/A	-	-	8.8	•	-
GT	9.0	-	-	7.2	-	-	N/A	-	-	10.1	-	-
SP-SYM	-	-	-	-	-	-	N/A	-	-	-	-	-
PARG	1.9	-	-	-	-	-	N/A	-	-	-	-	-
PLAG	40.8	-	-	43.4	-	-	N/A	-	-	44.0	•	-
P-PL	-	66.7	N/A	-	69.9	60.9	N/A	-	61.0	-	66.3	N/A
TI-AMP	6.9	-	-	4.3	•	-	N/A	-	-	3.4	-	-
ILN	3.9	3.87	N/A	1.0	1.0?	1.9	N/A	-	5.5	4.7	4.77	N/A
MT-USP	•	5,17	N/A	-	4.27	3.2	N/A	-	3.4	-	7.27	N/A
81	5.1	-	-	4.2	•	N/1	N/A	-	N/I	7.2	-	-
AP	0.4	0.4.	N/I	0.6	0.6	H/L	N/A	-	N/I	0.6	0.6	N/A
POINTS	959			1076	*********		N/A		*******	930		~~~~~~~~
AN/AN+AB			N/A			An51			An46			N/A

SAMPLE	850MSA-16	5		850MSD-68	)		840MSA-11	10		950M-230		
	POINT COUNT(2)	PRIMARY Recal	PROPS. PETMIX	POINT COUNT (2)	PRIMARY	PROPS. PETMIX	POINT COUNT(Z)	PRIMARY RECAL	PROPS. PETHIX	POINT COUNT(2)	PRIMARY RECAL	PROPS. PETMIX
DL	2.6	5.0	 9.6	7.0	9.2	14.0	. N/A	-	9.6	N/A		14.6
OPX	0.3	-	-	1.2	-	-	N/A	-	-	N/A	-	-
CPX	2.1	-	-	1.0	-	-	N/A	-	-	N/A	-	-
PCPX	12.3	12.3	10.1	5.6	5.6	13.4	N/A	-	18.8	N/A	-	13.6
GT-SYM	-	-	-	-	-	-	N/A	-	-	N/A	-	-
GT	15.2	•	-	12.7	-	-	N/A	-	-	N/A	-	•
SP-SYM	÷.	-	-	-	•	-	N/A	-	-	N/A	-	-
PARG	-	-	-	-	-	-	N/A	-	-	N/A	-	-
PLAG	39.0	-	-	50.1	-	-	N/A		-	N/A	-	-
P-PL	-	73.7	61.8	-	78.8	64.8	-	-	50.5	-	-	64.2
TI-AMP	19.5	-	•	16.0		· •	N/A	-	-	N/A	-	-
ILM	5.2	5.27	4.4	2.6	2.67	3.4	N/A	-	5.3	N/A	-	3.3
MT-USP	-	1.77	7.6	-	2.67	4.5	N/A	-	5.6	N/A	-	4.4
81	1.7	<1.7	N/1	2.6	<2 E	N/7	N/A		N/1	N/A	-	N/1
AP	1.3	1.3	N/I	0.7	0.7	N/1	N/A	-	N/I	N/A	-	N/T
POINTS	875	*********		1078	~~~~~~~~~		N/A		*******	N/A		*******
AN/AN+AB			An42			An48			An40			An48

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# <u>TABLE 5.66</u>: A comparison of cation proportions between the present composition, estimated primary compositions and the bulk rock.

850MSK-10	<b>S</b> 1	Ti	A1	Fe	Hg	Ca	Na	ĸ	Mg No
POINT COUNTS	43.2	1.2	17.7	10.8	12.4	8.7	5.3	0.6	0.53
PRIMARY (from points)	41.8	1.4	20.1	11.9	10.3	8.8	5.4	0.3	0.46
WIOLEROCK	42.6	1.4	18.8	10.4	12.3	7.9	5.8	0.8	0.54
85DHSA-82		• • • • • • •							
POINT COUNTS	43.8	1.0	17.7	9.8	13.6	7.8	5.6	0.6	0.58
PRIMARY (from points)	42.7	1.1	19.5	11.2	11.0	8.8	5.3	0.5	0.50
WHOLEROCK	42.8	1.4	18.5	10.0	13.5	7.6	5.2	0.8	0.57
840HS-13A	<u> </u>							<u> </u>	
POINT COUNTS	41.3	2.0	19.0	11.5	13.0	6.8	5.5	0.4	0.53
PRIMARY (from points)	41.4	2.3	21.6	12.7	8.1	7.6	5.0	0.3	0.39
HOLEROCK	43.2	1.3	20.6	8.8	10.6	7.7	6.0	0.9	0.55
850M\$-8									
POINT COUNTS	44.1	1.1	20.2	8.9	10.2	8.7	5.8	1.0	9,53
PRIMARY (from points)	42.4	1.2	20.9	11.8	8.9	0.0	5.7	0.3	0.43
HIOLERDCK	43.7	1.2	20.2	8.9	11.6	8.3	5.3	0.5	0.56
SDHSR-28			······						
POINT COUNTS	43.0	1.7	20.5	10.5	10 9	7 6			
PRIMARY (from points)	41.9	2.0	21.4	12.0	8.1	9.5	5.1	0.1	0.40
HOLEROCK	43.1	1.6	19.4	10.6	10.7	8.3	5.4	0.8	0.50

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zoning. However this is not the case because the combined Mg No. of product minerals agrees well with the olivine compositions given in Table 6.7. Thus the olivine composition probably did not change dramatically during corona growth.

### **VOLUME ESTIMATES OF CORONA PROPORTIONS**

Layer widths in the least-reacted coronites were determined directly with the microscope and by measurements on enlarged photomicrographs. The coronas are assumed to be spherical and this leads to successive estimates of the volume occupied by each layer, using the measured layer widths as increments to the radius of the olivine or opaque oxide core. In the olivine coronas the spherical model maximises the volume contribution of the outer shells, but as the olivine core is large relative to the narrow reaction rims, the errors are likely to be small and of similar magnitude to those in the incremental measurements of radii. Many coronas with large olivine cores were measured because these are likely to be the most representative sections through the centre of the corona. The volumes were converted to modal proportions using the molar volume data in Robie et al. (1979). It is stressed that this method can only provide rough estimates of the corona proportions, but these are still useful for considering mass transport and possible volume changes during corona growth.

Because the symplectite composition is inferred to reflect restricted mobility of Al and Si, the initial proportions of reactant olivine and plagioclase were estimated, as in Whitney & McLelland (1973) and Otten (1984) (section 6.3, this study), by assuming constant Al, Si. This results in a net volume decrease during corona growth. Unlike mass balance in the whole rock, constant volume cannot be used as a constraint in individual corona reactions because the corona phases are more dense than the reactants. The volume decrease can be balanced to some extent by the plagioclase in the surrounding matrix. formation Of sodic more Representative results from several samples are presented in Table 6.7 where the percentage refers to I gains (+), or losses (-) when backcalculating to the primary mineral proportions. The combined Mg number for reasonably consistent with the present olivine COTONA phases is. composition and again suggests that the olivine composition has not changed significantly during corona growth although, with the exception of 84DMS-13A, slightly more Mg appears to leave the corona interface. Presumably this is taken up in the formation of spinel clouding in

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850MSK-10	OPX	CPX	PARG	GT	AN55	Fo56	VOLUME	Si	Å1	Fe	Mg	Ca	Na	0	Mg No.
PRODUCTS	0.12	0.46		0.42			86.86	2.398	0.923	0.786	0.835	0.665	0.078	6.508	0.52
REACTANTS	-	-			0.148	0.953	102.32	2.398	0.923	0.829	1.077	0.318	0.247	8.548	Fo54-9
RESIDUALS	-	-	-	-	-	-	+15.46	-	-	+.043	+.244	347	+.169	+.040	
X CHANGE	-	-	-	-	-	-	+18%	-	-	+5%	+29%	-52%	+217%	+0.5%	
850MSR-82	OPX	CPX	PARG	GT	AN55	Fo59	VOLUME	\$1	A1	Fe	Mg	Ca	Na	0	Mg No.
PRODUCTS	0.32	0.34		0.33		******	 81.65	2.291	0.715	0.765	1.021	0.483	0.034	7.944	0.57
REACTANTS	-	-	-	-	0.115	1.172	98.88	2.291	0.715	0.961	1.383	0.247	0.192	8.368	Fo58-9
RESIDUALS	-	-	-	-	-	-	+17.23	_	-	+.196	+.362	236	+.158	+.424	
Z CHANGE	-	-	-	-	-	-	+21%	-	-	+26%	+36%	-49%	+465%	+5%	
840MS-13A	OPX	CPX	PARG	GT	AN55	Fo55	VOLUME	Si	A1	Fe	Mg	Ca	Na	0	Mg No.
PRODUCTS	0.37	0.20	0.14	0.29			109.13	2.869	0.991	0.962	1.277	0.586	0.141	10.140	0.57
REACTANTS	-	-	-	-	0.159	1.320	123.04	2,869	0.991	1.188	1.452	0.342	0.265	10.368	Fo53-55
RESIDUALS	-	-	-	-	-	-	+13.91	-	-	+.226	+.175	244	+.124	+.228	
X CHANGE	-	•	-	-	-	-	+13%	-	-	+24%	+14 <u>X</u>	-42%	+88%	+2%	
850MS-8	OPX	CPX	PARG	GT	ANSS	Fo58	VOLUME	Si	A1	Fe	Mg	Ca	Na	0	Mg No.
PRODUCTS	0.32	0.37		0.31			81.17	2.280	0.691	0.753	0.960	0,493	0.030	7.878	0.56
REACTANTS	-	-	-	-	0.111	1, 198	98.47	2.280	0.691	1.006	1.390	0.239	D. 185	8.344	Fo58-60
RESIDUALS	-	•	-	-	-	-	+17.30	-	-	+.253	+.430	254	+.155	+.466	
Z CHANGE	-	-	-	-	-	-	+21%	-	-	+34%	+45%	-52%	+516%	+6%	
850KSR28	OPX	CPX	PARG	GT	ANSS	Fo57	VOLUME	Si	A1	Fe	Mg	Ca	Na	0	Mg No.
PRODUCTS	0.31	0.28	-	0.40			84.92	2.379	0.847	0.897	0.984	0.466	a.026	8.406	0.52
REACTANTS	-	-	-	-	0.136	1.050	101.87	2.379	0.847	0.903	1.197	0.292	0.227	8.552	Fo55-8
RESIDUALS	-	-	-	_	-		+16.95			+.006	+.329	176	+.199	+.146	
Z CHANGE	-	-	-	-	· _	_		_	_	. 17	1227	-207	.7117	+27	

TABLE 5.7: An example of mass balance estimates around the olivine coronas in the least-evolved samples. The X change represents gains (+) or losses (-), as a X of the present cation proportions, to back-calculate the original olivine-plagioclase proportions involved in the corona reaction, based on constant Al,Si.

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plagioclase. As expected, a large amount of Ca must be added to the olplag reaction while Na is lost and this is discussed further in Chapter 7.

During formation of opaque oxide coronas Si was supplied solely by plagioclase so that mass balance depends critically on the reactant plagioclase composition. As a result small errors in the estimation of layer proportions demands significantly different plagioclase compositions to conserve Al and Si. In addition the shape and layer widths are highly variable and biotite may have formed partly or wholly by magmatic reaction. As a result the opaque coronas cannot be treated quantitatively with any degree of confidence. Nonetheless it has been found that titaniferous magnetite can supply the necessary Ti for biotite growth whereas, major additions of Ca. Mg, K  $\pm$  Si are required from beyond the corona interface.

### 6.4.4 MINERAL CHEMISTRY - STAGES II AND III

This section discusses the mineralogical changes during the formation of two pyroxene granulites or garnet amphibolites. Initially this involved the development of extensive monomineralic garnet rims and the establishment of a sodic plagioclase moat between garnet and pyroxene, while olivine the (gt-cpx) symplectite progressively disappeared. A and symplectite composed of opx-gt has been preserved in several Fe-rich 84DMSA-11F, 85DMSA-165, 84DMSA-(X-1) and 85DMSH-55), samples (e.g. although here the symplectite Al:Si ratio reflects a plagioclase moat rather than spinel-clouded plagioclase laths; e.g in 84DMSA-11F the ranges from An and represents an Al:Si of plagioclase moat approximately 0.44 to 0.47, while Al:Si in the symplectite ranges from 0.42 to 0.445 with a mean of 0.435 and provides further evidence that the bulk symplectite composition was influenced by the adjacent plagioclase composition.

#### Pyroxene

Coexisting garnet and pyroxene compositions are plotted in Figure 5.12a. Clinopyroxene recrystallises into a two pyroxene-plagioclase mosaic and in one sample, the exsolution of plagioclase was crystallographically



FIGURE 5.12b: Recalculated end-member garnet compositions from mean analyses of the evolved metagabbros (Stage III).



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controlled. As in Stage I, there is a positive correlation between Na and Al(oct) which is correlated with an increase in the Jd component.

### Plagioclase

The plagioclase moat composition was apparently in equilibrium with monomineralic garnet layers on one side and pyroxene (or olivine) on the other. The moat composition is variable, both within samples and between gabbroic clusters (Table 6.4). The variation within samples reflects more An-rich compositions adjacent to garnet, whereas the variation between clusters could be compatible with different pressures of metamorphism (section 6.8). Notably, in Opeongo subdomain the most varies from  $An_{24-29}$ while in the Kawagama zone, it ranges from An32-38 which is similar to that observed in many other samples; e.g. 85DMSH-5F (An<sub>22</sub>), 85DMSR-22  $(An_{32-34})$ , 84DMS-45A  $(An_{32-32})$  and 85DMSS-1B  $(An_{30-33})$ . However there is quite a variation in moat composition in the Huntsville area: 85DMSH-55 is most sodic (An<sub>21-23</sub>) whereas, 84DMSH-84C exhibits a wide range of compositions; less calcic (An 20-29) around pyroxene coronas while moats around primary clinopyroxene are An $_{3D-33}$ . The latter represents the most evolved corona-bearing sample which still retains pockets of relict plagioclase laths, consequently the variation in moat compositions probably reflects differential Ca-loss in the final stages of plagioclase recrystallisation and advanced garnet development.

During annealing, relict plagioclase laths exhibit a progressive decrease in the An-content relative to spinel-clouded plagioclase and range from An<sub>23-34</sub>. However complete textural reworking into granulites is accompanied by an increase in the An content, (up to  $An_{42-45}$  in 85DMSD-9 and  $An_{42-50}$  in 85DMSD-62C); in DMSD-9 the most calcic compositions are found in domains where pyroxene-plagioclase is extensively mantled by amphibole (section 6.6). In other samples the variation reflects reverse zoning with calcic rims.

#### Amphibole

Different samples define separate compositional fields and no distinct trends are observed. They all have similar Si contents and are pargasites or pargasitic hornblendes (Leake, 1978). The analyses were recalculated and converted to site occupancies and representative results are presented in Figure 6.13. The Ti content is variable and as in corona amphibole, it substitutes for Al(VI). There is a wide range in Na contents with a pronounced enrichment in 85DMSS-1B, especially with respect to the FIGURE 6.13: Site occupancies for amphiboles from evolved metagabbros.



corresponding granulite (85DMSS-1C). The amphibole in 85DMSS-1B is also rich in chlorine (1-1.4 Wt7) but with negligible flourine. There is a negative correlation between Na(M4) and total Ca content (Fig. 6.13b) with a slope of  $\approx$ -0.8, implying coupled substitution for Ca in the M4 site. Figure 6.13d portrays the positive correlation between increasing Al(tet) and the sum of Al(oct), Fe3 and Ti and represents Tschermaks substitution.

#### Garnet

Recalculated end-member compositions are shown in Figure 6.12b. The majority of analyses have similar Ca contents although the Fe/Mg ratios vary. The highest Ca-content occurs in 85DMSH-22 which also has the most extensive garnet development at the expense of plagioclase.

## 6.5 PHASE EQUILIBRIA AND THE EFFECTS OF WHOLE ROCK COMPOSITION

This section discusses a graphical and least-squares analysis of the evolving phase relations in metagabbroic rocks following Laird (1980) and Spear (1982). It has been adopted to determine if an overlap exists between various sub-assemblages within the metagabbros. A graphical approach is untenable for the overall coronite mineralogy because the coronas represent metastable products influenced by the local geochemical environment around olivine or opaque oxide grains. However it is possible to consider local equilibrium assemblages within individual coronas and plot these in diagrams to show possible reaction relationships and effects of whole rock composition. In assemblages that developed during textural reworking, where the fluid composition was probably an important additional constraint (section 6.6), important petrographic features to be considered include:

- 1) Garnet was apparently unstable in the anhydrous two-pyroxene granulites from Opeongo subdomain.
- In several samples garnet forms an equilibrium assemblage with clinopyroxene, although a plagioclase moat commonly separates the two.
- 3) In amphibolites, large garnet "spots" occur adjacent to plagioclase and relict primary clinopyroxene, the latter being replaced by amphibole.
- 4) In vein-networks the hydrous and anhydrous assemblages equibrated under the same P,T conditions but a reaction relation exists between them and may be related to fluid composition (section 6.6). Furthermore, in 85DMSS-1C garnet is found in both the amphibolite and pyroxene-

bearing domains but typically co-exists with clinopyroxene, while orthopyroxene was lost preferentially. In 85DMSD-9 garnet is only present in the amphibolite and marginal areas between domains, where amphibole has mantled pyroxene and orthopyroxene was replaced before clinopyroxene.

An ACF diagram is presented in Figure 6.14. After the breakdown of the olivine-plagioclase tie-line the whole rock analyses plot in the field of opx-cpx-plag for an amphibole-free system. In amphibole-bearing samples the bulk compositions fall within the field of hbl-gt-plag. In no case and in agreement with thin section observations, is orthopyroxene stable with garnet. Thus the incoming of amphibole stabilises garnet at the expense of pyroxene. However several samples show the stable coexistance of gt-cpx, e.g. 85DMSH-22, 85DMSS-18 etc. This assemblage is applicable in amphibolepoor assemblages and represents the replacement of the opx-plag tie-line by gt-cpx. The effect of plagioclase composition is demonstrated in the ACFN tetrahedrons (Figs. 6.14b & c).

Figure 6.15a portrays a projection of the coronite phase compositions from  $An_{38}$  onto the  $Al_2O_3$ -CaSiO\_3-MgSiO\_3 plane in the NFCAMS system and is achieved by condensing on the exchange vectors  $FeMg_1$  and  $NaSi(AlCa)_1$ . It illustrates the variable alumina contents in pyroxene and amphibole and again suggests that orthopyroxene should be unstable with gt-cpx for most bulk compositions. The effect of varying Fe/Mg is shown in Figure. 6.15b but this makes very little difference to the observed phase relationships.

There is no doubt that a reaction relationship exists in the vein-networks and that the phase volumes for the hydrous and anhydrous assemblages overlap (Greenwood, 1967). The details of the reaction relationships can be determined by modelling the bulk composition to the analysed phase compositions (Laird, 1980). Basically, if a reasonable fit to the bulk composition is obtained for each of the various subassemblages, then a reaction relationship must exist between them. This technique was applied using weighted least squares (Reid et al., 1973) and unlike the graphical approach, the full compositional variation can be represented in the SiO2-TiO2-Al2O3-Fe2O3-FeO-MnO-MgO-CaO-Na2O-K2O system. The results suggest that the bulk composition can be represented by the hydrous assemblage amph-plag-op±qtz whereas, under reduced water activity, opx-cpx-plag-op would be stable. However garnet is apparently unstable in both sub-assemblages and this is discussed further the following section.

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FIGURE 6.14: Triangular and tetrahedral ACF and ACFN diagrams for corona (a & b) and evolved metagabbros (c).



FIGURE 5.15: Projections from An<sub>38</sub> onto the Al<sub>2</sub>O<sub>3</sub>'-CaSiO<sub>3</sub>'-MgSiO<sub>3</sub>' plane by condensing on the exchange vectors FeMg<sub>1</sub> and NaSi(CaAl)<sub>1</sub> in the NFCMAS system; b demonstrates the effect of varying FeMg<sub>1</sub>.



Rotations are:



# 6.6 FLUID COMPOSITION

The least-evolved coronites effectively exhibit a granulite facies mineralogy and must have formed under reduced water activity because water would promote both reaction and deformation. Furthermore if the metagabbros had not acted as relatively competent bodies during deformation, the delicate coronas structures would not have been preserved as deformation promotes fluid influx and increases the available surface energy of reaction sites by grainsize reduction. As a consequence it was only when the "closed" rock environment broke down that the corona mineralogy became reconstituted. In high grade granulite facies rocks the most likely internal sources of H<sub>2</sub>O for retrogression is in intracrystalline sites (Barink, 1984), or within small melt fractions trapped along grain boundaries after anatexis (Pillar, 1985). External sources of water could be the adjacent dehydrating crust or a crystallising magma.

In sections 6.2.2 and 6.5 it was pointed out that the amount and composition of the fluid present had a considerable effect on the assemblages that developed during the metamorphic reconstitution of the igneous fabric (Table 5.2). Furthermore, as discussed in Chapter 5, section 5.4.6, upper amphibolite and granulite facies assemblages may form at the same P-T conditions but where reduced water activity, by either liberation of a melt or by dilution with CO, etc., stabilised dehydrated granulites. The water activity may be internally or externally controlled; i.e. by buffering or infiltration (Rice & Ferry, 1982). Infiltration prevails when the fluid is supplied from a source external to the rock medium and applies to both the dehydrating concept of "CO, flushing" (Newton et al. 1980) and to extensive hydrous retrogression. When the Composition of the fluid phase in equilibrium with the metamorphic assemblage is controlled by reactions within that assemblage, the rock is said to be internally buffered (Greenwood, 1975). In many cases, a combination of infiltration and internal buffering may prevail during metamorphism (Ferry & Burt, 1982); a restricted amount of fluid being supplied to the rock and the resulting fluid composition controlled (buffered) by the existing mineral assemblage. Many studies have attempted to quantify the composition of the metamorphic fluid but in this section. only a qualitative case study is presented.

# 6.6.1 LOCAL VARIATIONS IN FLUID COMPOSITION - Vein-networks

At locality DMSS-1 in the neck of Seguin subdomain (Fig. 3.7), evolved metagabbros display a variety of macroscopic fabrics, all within a few tens of metres (Chapter 3, section 3.6). The reconstituted samples vary from a gt-spotted rock (85DMSS-1A) to a foliated vein-network (85DMSS-1C). The vein-network (Plate 3.4c) consists of an anhydrous Pyroxene-plagioclase mesh around dark. hydrated amphibole-garnetplagioclase<u>+</u>biotite domains. At this locality the fabric has also been foliated and folded (Plate 3.4c). Both textures are common in other areas, but here they occur within the same gabbro body which is enclosed within migmatitic gneiss. Furthermore the sub-ophitic texture in the interior of the gabbro boudin has been preserved by almost complete garnet pseudomorphs of plagioclase laths (85DMSS-18, Plate 3.4b). This texture is developed to a lesser extent in other gabbroic boudins; notably 85DMSR-38, near the boundary between Rosseau and Moon River sub-domains. These three textural and mineralogical varieties are used as a case study to demonstrate the interplay between fluid composition and the assemblages that developed.

The major element chemistry of DMSS-1A (S-1A) and DMSS-1C (S-1C) are similar, whereas DMSS-18 (S-18) is richer in Ca,Fe,Ti relative to Mg. This probably reflects primary diferences in the amount of clinopyroxene and opaque oxide. However S-1B has been almost completely purged of potassium (0.05 Wt%) and is shown in the normalised incompatible element diagram in Figure 6.16. Here the analyses from S-1A and S-1C are similar to other metagabbros, but S-1B (and DMSR-38) are considerably depleted in the highly incompatible elements Rb, Ba and K. Another interesting feature of (and R-38) is that vanadium is approximately 4 times more both S-1B abundant (800-900 ppm c.f. 182-270 ppm in S-1A,1C), and this is comparable to V-contents in iron ores. Even in the most Fe, Ti-rich Opeongo samples, vanadium only contributes 400-500 ppm. Vanadium probably occurs in the state and because it has an octahedral radius approximately trivalent identical to Fe<sup>3+</sup>. it is found as a minor constituent in magnetite, amphibole and biotite (Landergren, 1978). In the samples clinopyroxene, described here it may be present in the neo-formed amphibole, ilmenite or Clinopyroxene. This implies, contrary to Eade and Fahrig (1973), that vanadium given the right conditions, may not be an immobile element under high grade metamorphism.

FIGURE 5.16: Normalised incompatible element "spidergrams" for selected evolved metagabbros. The field of proposed parental liquids for coronites has been superimposed for comparison.



WD microprobe analyses were carried out on samples S-1C and S-18. Clinopyroxene has a similar composition in both, although Na is enriched in S-1B. Garnet in S-1C is richer in grossular at the expense of pyrope (i.e.  $CaMg_{-1}$  exchange, Fig. 6.12b). In S-1B clinopyroxene occurs as large, poikiloblastic cpx-plag plates, where both are commonly in optical continuity. Amphibole mantles cpx, opaques and contains inclusions of garnet and thus is syn- and post-extensive garnet growth. However in the vein-network (S-1C), amphibole has only replaced pyroxene within specific domains and is associated with gt-plag+biotite. Clinopyroxene forms fine grained poikiloblastic and granoblastic intergrowths with orthopyroxene, plagioclase and a little quartz which together, forms the network around the hydrous domains. Plagioclase is more calcic in the vein-network  $(An_{42-9})$  whereas in S-1B it is sodic ranging from  $An_{23-34}$ , where more calcic compositions  $(An_{11-4})$  are present next to garnet.

Amphibole is the only hydrous phase present in sufficient amounts to have a significant buffering capacity and its composition can be used to infer the fluid composition. In DMSS-18, amphibole contains 1-1.4 Wt1 chlorine whereas in S-1C and other vein-networks (e.g. 85DMSD-9), Cl only contributes 0.04-0.24 Wt1. Both have negligible fluorine. In addition amphibole is more sodic in S-18 (Fig. 6.13b,e) and it substituted for both K in the A-site and Ca in the M4 site (Fig. 6.13b). As the whole rock Na contents are similar in all three samples from this locality, the high Na content of amphiboles must reflect extensive garnet growth at the expense of plagioclase, rather than being introduced by infiltration metasomatism. Thus it appears that during metamorphism the infiltrating fluid was

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locally rich in Cl and probably V. Furthermore chlorine is probably almost completely associated at the elevated P,T conditions of metamorphism, occurring in the form of NaCl, and in contrast to fluorine, it strongly partitions into the fluid relative to mineral phases (Ferry & Burt, 1982). Thus its presence in silicates suggests that the fluid contained significant amounts of chlorine. In addition, because Cl partitions preferentially into the fluid phase, the rock must have remained closed to further fluid influx as this would undoubtedly purge Cl from amphibole.

In vein-networks, the patchy anhydrous fabric is also a function of reduced water activity; amphibole acted as an internal buffer for  $H_0 O_2^0$  where the amount of amphibole development and hence garnet (by the breakdown of opx-cpx+amphibole) was controlled by the water activity through generalised equations such as:

Opx + Cpx + An<sub>As</sub> + Fe-oxides + H<sub>2</sub>O  $\rightarrow$  Amph + Qtz

Cpx + Fe-oxides +  $An_{4c}$  +  $H_{2}$  0 + Gt + Amph + Qtz

By Le Chatelier's principle, greater availability of water on the LHS results in more amphibole formation whereas, under less hydrous conditions, two-pyroxene granulites form. Presumably water from the surrounding migmatites infiltrated the metagabbros which then internally buffered the fluid composition. This must have occurred after extensive Cl infiltration. A later restricted influx of  $H_2O$  resulted in vein-networks and gt-spotted amphibolites where the metamorphic assemblage acted as an internal buffer on the fluid composition and prevented hydration of S-1B in the core of the body.

In a vein-network from the Kawagama zone (85DMSD-9) plagioclase is notably more calcic in the amphibole-bearing domains  $\{An_{43-45}\}$ , compared with  $An_{34-37}$  in pyroxene-bearing domains undergoing retrogression. In addition in contrast to DMSS-1C, garnet is not observed next to opx-cpxplag and is only present in the amphibole domains where there is very little relict pyroxene. This implies that amphibole was a necessary prerequisite for garnet formation which may have involved coupled reactions such as:

210px + 18Cpx + 5Fe-oxides + 22An<sub>37</sub> + 32H<sub>2</sub>0  $\rightarrow$  25Qtz + 16Amph + 17An<sub>46</sub> 9Qtz +  $\delta An_{46}$  + 4Amph + 1Fe-oxide  $\rightarrow$  5Gt +  $\delta An_{37}$  + 7Cpx + 7H<sub>2</sub>0 overall (conserving cpx):

210px + 7Fe-oxides + 7An<sub>37</sub> + 14H<sub>2</sub>0  $\rightarrow$  20tz + 2An<sub>46</sub> + 5Amph + 13Gt

# PART C: THEORETICAL AND P-T EVALUATION OF REACTIONS

## 6.7 GRESEN'S TECHNIQUE

The corona reaction can be considered in terms of composition and volume changes across each reaction interface. Both can be evaluated using the method of Gresens (1967) which was applied to olivine coronas by Joesten (1986a & b). Unlike the results in Table 6.7 where Al,Si was conserved, this technique makes no assumptions about relative component mobilities and solves for a range of volume factors (f); the amount of each component evolved or consumed depending linearly on the volume of product assemblage formed to volume of reactant consumed. The constant of proportionality is the volume factor and this has a value of one when the volume remains unchanged, < 1 for a decrease in volume and > 1 for a volume increase. The stoichiometric coefficient (v<sub>1</sub>) for each component evolved (-) or consumed (+) is given by the equation:

 $v_{i} = -\{[f_{v}(v^{A}/v^{B})n_{i}^{B}] - n_{i}^{A}\}$ 

where V represents the molar volumes of phases A and 8, and  $n_i$  the number of moles of component i per formula unit of assemblage A or 8. Results from the application of this method to opx-cpx-(cxp-gt)sym and op-cpx-parg-(parg-gt)sym coronas are presented in Figure 6.17. At the plagioclase interface they are dependent on the composition of both plagioclase and the symplectite, both of which vary and whose original composition is uncertain. However it is possible for no Al.Si to be liberated from the plagioclase interface ( $v_i = 0$ ) at a volume factor of approximately -0.95 to 1.0, if the mean symplectite and intermediate plagioclase compositions (around An<sub>ic</sub>) are applied.

# 6.8 P-T PATH FOR THE REACTION HISTORY

This section attempts to constrain P.T conditions through Stages I, II and III of the textural evolution described in section 6.2. Here it was proposed that textures in Stage I reflected reaction during subsolidus cooling from magmatic temperatures, whereas Stages II and III represent metamorphic reworking. Although coronas represent textural disequilibrium,

FIGURE 6.17: Variation in stoichiometric coefficents (vi) for each reaction interface using the technique of Gresens (1957). Mass transfer scaled to 100 cm3 of product formed at each interface.



the consistent phase relations discussed in section 6.4 suggest that at least local equilibrium applied to the continuous solid solution reactions. As a consequence further compositional readjustments during subsequent metamorphism are also likely. Johnson & Essene (1982) invoked the latter proposal in a study of garnet formation in olivine-bearing metagabbros from the Adirondack and ascribed the apparent textural disequilibrium to low water fugacity inhibiting recrystallisation. However, in the CGB a complete textural history has been preserved and various geothermometers and barometers have been applied to determine if P.T discrepancies between different stages do exist. The thermobarometers are discussed in Chapter 5, section 5.4 and the results from their application are presented in Table 6.8 and Figures 6.18 & 6.19. Figure 6.18 includes a petrogenetic grid from recent experimental and theoretical studies in the CMAS and CFAS systems (Johnson & Essene, 1982; Bohlen et al., 1983b respectively). The curves are strongly pressure dependent and the addition of Fe depresses the garnet-forming reactions to lower pressures. The main mineralogical difference between the two systems is that spinel is not stable in CFAS because olivine-plagioclase breaks down directly to garnet. In the natural, multi-component system these univariant reactions will become at least divariant fields and olivine-plagioclase will become unstable at intermediate pressures between the two garnet-producing, endmember reactions. Indeed all pressure estimates straddle or lie just below the first univariant garnet reaction in CMAS.

Pressure determinations in the least evolved coronites employed the olivine-plagioclase-garnet barometer of Bohlen et al. (1983b). This assumes that olivine was in compositional equilibrium with both corona garnet and spinel-clouded or moat plagioclase, the latter depending on whether a moat is present (i.e as in samples from Stage II); in some case both have been used, although the establishment of a moat suggests that lath compositions are out of "equilibrium" with garnet and olivine and the erroneously low pressures in samples from Stage II in Table 6.8 suggest this is the case. Intuitively the most sodic, spinel-clouded plagioclase should reflect higher equilibration pressures and should be a more reliable pressure indicator than cation partitioning because it forms by discontinuous reactions and as expected, the highest pressure estimates of 9-10.5 Kbars come from 85DMSR-82 and 85DMSK-10. In the latter example this is consistent with the higher jadeite content in clinopyroxene (Fig.6.7b). However the corresponding grossular content in garnet should exhibit a slight decrease with pressure (Gasparik, 1987; section 8.9 this study) but

TABLE 6.8: P-T estimates from metagabbros (abbreviations I, II etc. refer to the stage in Table 6.1 & 6.2; \* refers to pressure determinations using a plagioclase moat composition).

SUBDOMAIN		THERMO	BAROMETR	Υ	
60 HOME	GT-CPX (E & G1	GT-HOLLG &	P] [WELLS]	GT-OL-PLAG (Boh et a	1.1
86DMS-18 (I)	630-670(+50-70°C)			8-8.5Kb (An41-2)	
850MS-6 (I;ED)	630-750(+0-50°C)	-		8.4-9.2Kb (An42)	
85DMS-7 (1)	680-710(+40-70°C)	-		8.5-9.6Kb (An40)	
850MS-8 (1)	705-755(+10-30°C)	-		8.4-9.8Kb (An41)	
84DMS-13A (I)	710-770(+30-70°C)	675-700	685-725°	8-8.9Kb (An38)	
84DMS-19 (I)	725-775(+20-50°C)	670-675	690-700°	-	
840MS-45A (III;ED)	- ,	650-675	675-700 <sup>0</sup> 1	-	
OPEONGO	GT-CPX (E & G)	GT-OPX (HAR)	[S & B]	GT-HBLEG & PJ [WELLS]	GT-OL-PLAGIBoh et al.]
84DMSA-2A (ED;III)		630-710	720-830°(	660-685 700-730	-
85DMSA-88 (IIa)	690-740(+20-50°C)	-	-	-	6.7-7.1Kb (An41)
850MSA-11A (IIa)	680-715(+60-80°C)	-		-	5.8-6.5Kb (An41)
84DMSA-11F (IIa)	700-740(+30-60°C)	710-740	800-850°0	-	7-8Kb (An41)
84DMSA-11G (ED:III)	640-730(+30-90°C)7	620-700	670-770°0	-	-
850MSA-138 (11a)	-	700-760	815-900°C	- *7.6	-8.3(An26) 6.3-7(An38)
840MSA-13N (11a)	750-950(+30-70°C)	700-725	820-845°C	710-760 725-775 *7.	6-8.5(An27) 6.5-7.2(An39)
850MSA-13P (111)	2670-7451-10-12000	660-715	750-830 0		-
850MSA-165 (IIa)	705-735(+30-50°C)	-	100-000 0	- *7.	4-8.4(An29) 6.5-7.2(An41)
HUNTSVILLE	GT-CPX [E & G]	GT-OPX [HAR]	[S & B]	GT-CPX-PLAG-QTZ (N & P)	GT-OL-PLAG(Boh et al.)
85DMSH-5F (11)	680-740(+30-50°C)	*********			
850MSH-186 (ED:111)	535-660(+90-120°C)	-		-	-
85DMSH-228 (111)	730-775(+20-40 <sup>0</sup> C)	-		6.1-7.5 Kbars	-
850MSH-55 (111)	695-785(+30-60 <sup>0</sup> C)	710-760	825-895 0	-	8.2-9.6 Kb (An20-23)
85DMSH-84C (II)	705-750(+40-50°C)	-	023-033 6	-	-
SEGUIN	GT-CPX (E & G)	GT-OPX [HAR]	[S & B] G	T-OPX-PLAG-QTZ [P & C]	GT-OL-PLAG[Boh et al.]
850MSS-18 (III)	710-750(+30-60°C)		******	[Mg] - (Fe]	
850MSS-1C (111)	725-765(+40-50°C)	710-750	830-875 8	.9-9.9kb 8-9.1(max., no q	tz) -
850MSH-4C (ED:11)	650-700(+50-70°C)	-		-	8-8.9(An25) 7-7.8(An34)
850MSH-46 (11)	640-680(+60-90°C)	-		-	8.4-9.3kb (An35-39)
850MSH101C (II)	620-670(+50-95°C)	-		-	7-8.5Kb (An28-34)
ROSSEAU	GT-CPX (E & G)	GT-HBLLG & P	] [WELLS]	GT-OL-PLAG(Boh et al.)	
850MSR-22 (ED;II)	7675-735(+10-120°C)	630-700	720-810	*	
850MSR-28 (I)	675-695(+25-35°C)	-		8.5-9.7Kb (An36)	
850MSR-30 (ED:1)	625-700(+50-100°C)	-		7.2-9.2Kb (An27-38)	
850MSR-82 (1)	610-690(+60-120°C)	-		9.1-10.1Kb (An30-33)	
KAWAGAMA	GT-CPX [E & G]	GT-OPX [HAR]	[S & B] G	T-OPX-PLAG-QTZ (P & C)	GT-OL-PLAG(Boh et al.)
85DMSD-9 (III)	745-775(+20-40°C)	680-750	 790-850°C	9.3-10.5(Mg) 7.6-8.8(Fe)	
850MS0-62C (111)	735-780(+50-70°C)	785-810	915-940°C	9.2-10.2[Mg] 10-11[Fe](ma:	x,no qtz) —
850MSD-68 (IIa)	700-730(+50-60°C)	•		* *	7.5-8.5(Ån35) 7.0-7.5(Ån42)
KIOSK	GT-CPX (E & G)	GT-HBLIG & PI	(WELLS)	GT-OL-PLAGIBoh et al.)	
85DMSK-2	730-775(+10-70°C)	650-710	650-680°C	7.8-9.3Kb (An30-40)	
850MSK-10	685-725(+40-80°C)	-		8.8-10.5Kb (An25-33)	
850M-230 (IIa)	700-750(+30-70°C)	-		*****	0.2-9.6Kb (Ån30)

,

FIGURE 6.18: Experimental and theoretical reaction curves in CMAS (----) and CFAS (---) with P.T estimates from ol-plag-gt barometry and gt-cpx, gt-opx thermometry superimposed.



FOOTNOTE: The calculated equilibria in CMAS are from Johnson and Essene (1982) and the reaction Fo + An = Gr<sub>1</sub>Pyr<sub>2</sub> is metastable. Equilibria in CFAS are from Bohlen et al. (1983a) where the equilibrium involving pure grossular and almandine is metastable with respect to that involving the Ca-Fe garnet solid solution. this is not so in 85DMSK-10 where high grossular contents correlate with the most Ca-depleted plagioclase (Fig. 5.10a). The highest pressure estimates from 85DMSK-10 corresponds to conditions that favoured both garnet and significant spinel formation in olivine coronas. This implies that the rock must have passed through the spinel field at relatively high pressures. The only means of achieving this (Fig. 6.1) is cooling coupled with a pressure increase, or cooling at high pressures following intrusion at around 40 km in the crust, because the prograde origin cannot explain why spinel is rare or absent in other unevolved coronites where the initial pressures, based on the An-content of plagioclase, were probably lower.

In general pressure estimates from coronites in Stage I and II range from 8-10 Kbars but this is consistently lower in the evolved samples from Opeongo and Kawagama, where a plagioclase moat has formed between olivine<u>+</u> orthopyroxene and garnet. Although the pressure differences are not significant (i.e. just within the ±1-2 Kbar error for the geobarometer), they do agree with the similarly lower pressure estimates from the corresponding host granulites and provide an independent test on the reliability of thermobarometry in both lithologies. This is also broadly consistent with the phase relationships for vein-networks and reworked metagabbros in these two areas, where garnet was apparently unstable with pyroxene. The slightly lower pressures may correlate with the first granulite isograd (OPX-CPX) of Engel & Engel (1962). In Seguin subdomain the migmatitic host gneisses do not contain assemblages suitable for geothermobarometry but opx-gt-plag-qtz barometry (Perkins & Chipera, 1985) in a gabbroic veinnetwork (85DMSS-1C) implies pressures of 9-10 Kbars and here garnet is found in the pyroxene-bearing domains.

The comparable pressures for assemblages in coronites and veinnetworks exist despite the fact that the coronites were intruded at least 100 Ma. prior to the granulite facies metamorphism. Thus it is only evidence from (1) a comparison with coronites from other granulite facies terranes, (2) the energetics of mineral transformation (section 6.2.1) and (3) the metastable coexistance of spinel- and garnet-bearing symplectites in the texturally unevolved samples with the lowest An-content in plagioclase and highest Jd in cpx (refer section 6.9), that favours an origin by cooling from magmatic temperatures. Temperature estimates from gt-cpx thermometry (Ellis & Green, 1979) are similarly indistinguishable from those in the host gneisses and in both cases, probably represent the blocking temperature from the peak metamorphic conditions. However application of the graphical two pyroxene thermometer (Lindsley, 1983) results in equilibration temperatures of  $750-950^{\circ}$ C for clinopyroxene (Fig. 6.19a) and reset values of  $\sim 600-700^{\circ}$ C for orthopyroxene. If real, the clinopyroxene estimates may represent closure temperature for Ca exchange during cooling, whereas the Fe-Mg partitioning used in gt-cpx thermometry presumably continually reequilibrated during cooling and subsequent metamorphism. This is substantiated to some extent in that clinopyroxene in evolved and reconstituted samples (85DMSS-1C, 85DMSD-9 and 84DMSA-9A) produces lower temperatures (Fig. 6.19a), comparable to the estimates from the host gneisses.

Recent experimental work by Gasparik (1987) produced the phase presented in Figure 6.19b & c where correponding mean diagrams compositions for corona phases from the CGB have been superimposed. The results are ambiguous and the graphical thermobarometers do not appear to accomodate the relatively large range in bulk composition represented by the metagabbros; in each case, Fe-rich samples always give considerably lower pressure estimates (5-7 Kbars) than more magnesian metagabbros (7-9 Kbars). The most Fe-rich samples do come from Opeongo where the pressures may have been slightly lower, but other clusters also exhibit a range of Mg Nos. and these similarly give conflicting P,T estimates. In many instances there is a compostional correlation which cuts across the P.T isopleths and implies that the gradients are not true reflections of the phase relations. The correspondence is better for magnesian metagabbros where estimated pressures of 7-9 Kbars are broadly consistent with ol-plag-gt barometry although temperature estimates are still scattered. Furthermore the thermobarometer based on the Al content of orthopyroxene produces erroneously low temperatures ( $\Delta s$  in Fig. 6.19c). This reflects the disequilibrium distribution of Al because restricted mobility of Al rate-limiting during corona growth (Chapter 7), whereas other was components had time to adopt at least a local equilibrium partitioning. Texturally reworked and recrytallised samples have consistently higher X<sup>Dpx</sup> and the results from  $opx(X_{k1}) - opx(X_{F_k})$  and  $opx(X_{F_k}) - plag(X_{k1})$  are consequently closer and may coincide. Thus thermobarometry using the Al content in pyroxene should not be applied to coronas or to any other assemblages where there is evidence of textural disequilibrium promoted by

FIGURE 6.19: Graphical geothermobarometry: a - Lindsley & Anderson (1983) two pyroxene thermometer with field for granulites superimposed ( );

- b Thermobarometry based on the Fe-content of ol.opx,gt and spinel;
- c Phase relations in NFCMAS where isopleths indicates the Fe and Alcontent of opx (solid) and An-content of plag (dashed isopleths).





c)



slow rates of Al-diffusion. Gasparik (1987) suggested that the An-content of spinel-clouded plagioclase in the Adirondack samples did not reach equilibrium. However this is not borne out here where it appears to have approached a consistent equilibrium composition throughout the unevolved coronites. During subsequent textural reworking it adopted more sodic compositions in the form of a plagiolcase moat, where greater garnet development was responsible for the further depleting the An-content of plagioclase.

In summary quantitative pressure estimates are not conclusive with regard to the mode of origin of coronas and they can represent a) resetting of either path 1 or 2 in Figure 6.1 by continuous cation exchange; or b) fortuitous intrusion and cooling at analogous depths to the metamorphic equilibration some 100 Ma. later. Hypothesis a) is analogous to Johnson & Essene (1982) who inferred that coronal minerals re-equilibrated at or near the peak metamorphic conditions, irrespective of their initial mode of origin. If so the metagabbros corroborate the pressure estimates in the host gneisses by independent barometry, both suggesting a small pressure decrease towards the east and southeast of the area under study.

# 6.9 PHASE EQUILIBRIA - GIBB'S METHOD

In this section implications from the subtle compositional variations in coronites and vein-networks are considered using the Gibb's method. how intensive variables of metamorphism, such as This determines composition, chemical potential, temperature and pressure relate to one another and may provide addional constraints on the P-T path of the complicated reaction history. A full discussion of the method is given by Rumble (1976) and Spear et al. (1982b). The latter formulated analytical solutions for variables such as  $dX_1/dP_2$ ,  $d\mu/dP_2$ , dP/dT etc. by matrix manipulation of linear equations describing a variety of systems. However because of the large size of the matrix necessary to describe a multicomponent olivine corona, only a numerical solution has been attempted here. The resulting terms are subject to large uncertainties that arise from the available thermodynamic data and the simplified mixing properties of the phases concerned. Thus absolute values should be treated with caution although the sign and relative magnitude of terms may prove to be useful and are discussed below. The thermodynamic abbreviations are given

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in Appendix IV.

In Stage I olivine coronas contain basically the same mineral assemblage involving ol-opx-cpx-gt-plag. The compositional variations are continuous and are represented by a) the amount of jadeite in clinopyroxene; b) the grossular content of garnet; c) the fayalite content of olivine and d) the anorthite content of plagioclase. The Gibb's technique has been adopted to assess theoretically how these compositional parameters relate to both one another and to varying pressure. This has been Carried out for three samples with varying amounts of Jd, Gross and An phase components. The method involves the selection of components that describe the chemical variability of the assemblage then, following Spear et al. (1982a) and Thompson (1982), the chemical variability of each phase is expressed in terms of phase components. A Gibb's-Duhem equation (SdT-VdP+EX,  $d\mu_i = 0$ ) can then be written for each phase together with a linear, independent set of heterogeneous equilibrium conditions. Finally additional equations are included to determine how the compositional variables (dX,) inter-relate to one another, or to other intensive variables of metamorphism. The choice of dX, is completely arbitrary and depends only on what compositional parameters are desired. The compositional terms  $dX_i^{\Phi}$  are related to the curvature of the Gibb's Free energy surface (G,) for that phase ( $\phi$ ) by equations of the form (for a simple binary solution):

$$d\{\mu_{2}^{A}-\mu_{1}^{A}\} = -(S_{2}^{A}-S_{1}^{A})dT + (V_{2}^{A}-V_{1}^{A})dP + (d^{2}(G_{A})/d(X_{2}^{A})^{2})_{P,T}dX_{2}^{A} \dots (1)$$

Higher order solid solutions require additional equations and crosscurvature terms for the Gibb's function.

The equations developed here follow Sack (1980a & b) who formulated petrogenetic grids in the NFCMAS system for mafic granulites from the Adirondack Highlands, New York state. Sack (1980a & b) considered the topology of the six univariant 5-phase assemblages radiating from the invariant 6-phase assemblage ol-opx-cpx-gt-plag-spinel at fixed P,T. His results suggest that the invariant point is located at  $Fa_{34}$ ,  $An_{41}$  or  $Fa_{34}$ , Gross<sub>19</sub>. The corresponding univariant asemblage applicable to the olivine coronas described here is ol-opx-cpx-gt-plag.

Various thermodynamic mixing models and interaction paramters  $\binom{W}{ij}$  have been applied to derive the curvature of the Gibb's function for

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variations on equation (1) above. All the mixing properties are known to be non-ideal and various models, invoking different assumptions, are described in the literature. The mixing model for pyroxene is most problematic because there is no adequate formulation of its mixing properties: Saxena et al. (1986) evaluated Margules parameters for quadrilateral components but this does not take into account Na and Al substitution although Ganguly (1973) suggested that jadeite forms an almost ideal solid solution with diopside, while Gasparik (1987) suggested that the Al-content made very little difference to the predicted quadrilateral distribution following Lindsley (1983). Because of these Uncertainties the empirical cpx formulation of Sack (1980b) is adopted here. For garnets a variety of symmetric regular solution and asymmetric mixing models are available and three have been adopted for comparison here: Ganguly & Kennedy (1974), Perkins (1979) - symmetric; Sack (1980b) asymmetric; Ganguly & Saxena (1984) - asymmetric and includes a ternary interaction parameter ( $W_{123}$ ). Each result in significantly different values for the Gibb's curvature term. Two formulations are available for the mixing properties of plagiolcase: the experimentally determined activity data of Orville (1972) and the theoretical model of Newton (1983). Each gives slightly different values for the curvature of the Gibb's energy function  $\{G_{A,A,A,n}\}$ . The interdependence of grossular, jadeite, anorthite and fayalite compositional parameters in the 5-phase assemblage can then be derived at constant P.T for each mixing model and compared with the observed mineral chemistry.

The change of various compositional parameters with respect to pressure and temperature (i.e.  $(\partial X_i / \partial P)_T$ ,  $(\partial X_i / \partial T)_P$ ) can be deduced from the six-phase assemblage and the necessary equations are given in Sack (1980b). Volume terms are known with sufficient accuracy to attach importance to differentials with respect to pressure, but the uncertainty in the available entropy and enthalpy data negates the significance of differentials with respect to temperature. Again it is stressed that although absolute values may not be meaningful, the sign and relative magnitude of the differentials are important for qualitatively evaluating how various compositional parameters change with pressure.

The molar volumes for end-member components, apart from garnet, were taken from Robie et al. (1979) and volumes for solid solutions derived using the simple expression  $V_i \varphi = \Sigma_i X_i V_i \varphi$ . Garnet molar volumes were determined from Cressey et al. (1978) where because of the substantial

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deviation from ideality in garnet solid solutions involving grossular, garnet in DMSK-10, although the most calcic, occupies a smaller volume than garnet in DMS-8 and DMSR-82.

### **6.9.1 DISCUSSION**

Results for various compositional differentials at constant P.T in the five-phase corona assemblage are presented in Table 6.9a. The effect of various mixing parameters are shown with respect to DMSK-10. Asymmetric garnet models produce significantly different results from the symmetric regular solution model of Ganguly & Kennedy (1974) (and Perkins, 1979). This is because the latter formulation results in very small Margules parameters for the binary Alm-Gross solid solution and results in a negative cross curvature term for the Gibb's function.

However, with the exception of the small +ve to -ve slope for  $(\partial X_{GP} / \partial X_{AR})_{P,T}$ , the sign of all compositional gradients are equivalent and as a result, the following observation can be made with respect to decreasing An content in spinel-clouded plagioclase at fixed P and T:

- 1) The amount of almandine in garnet and hedenbergite in clinopyroxene increases.
- Grossular in garnet increases with Ganguly & Kennedy (1974), but is approximately independent of the An content in asymmetric garnet mixing models (i.e. small +ve to -ve slope).
- 3) The En, CaTs and Jd components in clinopyroxene all decrease.

With increasing Fa in olivine the following occurs:

- There is a decrease in Jd,CaTs. En within clinopyroxene and in the An content of plagioclase. This is consistent with Table 6.6a where the recalculated pimary plagioclase composition were apparently more sodic in the Fe-rich metagabbros.
- 2) Grossular is approximately constant.
- 3) Alm in garnet increases.

Composition variables with respect to pressure are obtained from the six-phase assemblage ol-opx-cpx-gt-plag-spin. Here, irrespective of the mixing model, the sign of the differentials are constant and the following qualitative observations can be made with increasing pressure: • , •

TABLE 6. 9a: Partial differentials at fixed P and T from a phase equilibria study of the five-phase corona assemblage, using mixing models of Sack (1980a). Ganguly & Kennedy (1974), Ganguly & Saxena (1984), Orville (1972) and Newton (1983).

SANPLE	HIXING HODEL	9XYI=\9XYU	OX6+/OXAn	9XH+4/9XYU	<b>ƏXEn/ƏXAn</b>	axcats/axin	u x X6 / b E X6	2
	Sack, Orville	-0.81	-0.02	-0.80	+0.04	+0.03	+0.34	
850HSX-10	GLK, Orville	-2.31	-0.72	•	•	•	•	
	ELS, Orville	-0.75	+0.03	-	•	•	•	
	GES, Newton	-0.61	+0.03	-0.65	+0.04	+0.02	+0.28	
850HSR-82	G&S, Orville	-0.67	0.00	-0.50	+0.02	+0.08	+0.10	
850H3-8	GES, Orville	-0.57	0.00	-0.52	+0.02	+0.13	+0.05	
SANPLE	NIXING HODEL	dxalm/dxFa	ðx6r/ðxFa	∂xH•d/∂XF≥	ðXEn/ðXFa	ðxcats/ðxfa	dXJd/dXFa	dxxn/dxF
	Sack, Orville	+0.48	+0.01	+0.47	-0.03	-0.02	-0.20	-0.59
85DHSK-10	S&K, Orville	+1.37	+0.43	•	•	•	•	•
	G&S, Orville	+0.44	-0.02	•	•	•	•	
	SLS. Newton	•		•	-	•	•	-0.74

TABLE 6.9 b: Partial differentials with respect to pressure in the six-phase assemblage at constant T.

SAMPLE	HIXING MODEL	dxalm/dP	∂xsr/∂P	∂xH+4/∂P	OXEn/ OP	dxcate/dP	9234/96	AVY UT YOU
•50MSK~10	Sack, Grville G&K. Grville	-0.19	-1.07	-1,14	+0.40	-0.03	+3.72	-6.76
	G&S, Drville G&S, Newton	-0.16	-0.59	•		:	•	• • • . 32
\$50HSR-82	045, Orville	-0.69	-0.49	-1,08	+0.30	-0.08	+2.36	-7.88
450HS-6	G&S, Orville	-0.81	-0.50	-1.18	+0.43	-0.13	+2.24	-8.55

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- Alm and Gross contents in garnet decrease. This is expected as both have greater molar volumes than pyrope and agrees with the observation of Gasparik (1987) and O'Neill (1981), the latter on the transition between spinel and garnet lherzolites.
- 2) More importantly and as expected from experimental work, An decreases and Jd increases. This is consistent with the mineral chemistry and the corresponding thermobarometric estimates in section 6.8 where DMSK-10 contains the highest Jd content and most sodic spinel-clouded plagioclase. DMSK-10 also contains the most calcic garnet and this is problematic. However Ellis & Green (1979) provide experimental evidence for a positive correlation between  $X_{Ca}^{Gt}$  and temperature at a fixed  $K_0$  $(X_{Fe}^{Gt}, X_{Hg}^{Cpx}/X_{Hg}^{Gt}, X_{Fe}^{Cpx})$ , and thus it is possible that the high grossular content may correlate with higher temperature conditions; i.e. reactions frozen at higher temperatures during subsolidus cooling. In contrast, Gasparik (1987) suggests the temperature dependance of grossular is negligible.

### 6.10 CONCLUSIONS

Gabbroic rocks were intruded into a gneissic basement around 1.2 Ga. and document a complex reaction history through the latter part of the Grenvillian orogeny. The initial reactions resulted in coronas that separated plagioclase from olivine and opaque oxide. Plagioclase became progressively more sodic during the process and liberated Ca for corona growth, the resulting excess alumina being exsolved as fine grained spinel "dust". The coronas consist of inner, low-alumina layers (opx,cpx) surrounded by a garnet-bearing symplectite <u>+</u> pargasitic amphibole. Spinelbearing symplectites are very rare and when present, coexists metastably with garnet-clinopyroxene symplectites, both being later replaced by monomineralic garnet during the textural evolution.

In the subsequent evolution it is proposed that that higher energy conditions during prograde metamorphism resulted in the variable reconstitution of coronites into either garnet amphibolites or two pyroxene granulites, depending on the fluid activity. Initially this involved annealing of spinel into discrete spinel blades oriented along crystallographic directions in relict plagioclase laths, and the replacement of the (gt-cpx) symplectite by monomineralic garnet. At the

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same stage a sodic plagioclase moat began to develop between the pyroxene core ( $\pm$  olivine) and monomineralic garnet. Eventually matrix plagioclase recrystallised into a granoblastic mosaic. Primary clinopyroxene did not take part in the early corona-forming reactions and helped to preserve the macroscopic, sub-ophitic fabric until quite advance stages of reaction when the gabbros eventually became completely reconstituted. In some instances both amphibolite and granulite facies assemblages coexist within one body and this provides strong evidence for internal buffering of the fluid activity by the reactions taking place within the rock.

Coronas have been documented in other granulite facies terranes where spinel-bearing symplectites are common. As in the CGB these have been variably replaced by monomineralic garnet. If a prograde origin is invoked to explain initial corona growth, it seems unlikely that the CGB metagabbros could fortuitously survive the spinel stability field while other terranes did not. However if the corona reactions were initiated by slow, subsolidus cooling from magmatic temperatures, then the CGB gabbros could have been intruded at greater depths. Furthermore one of the least reacted samples contains both the most sodic spinel-clouded plagioclase together with a significant amount of metastable spinel symplectite. Here the lower An-content of plagioclase implies the highest equilibration pressures and only a mechanism invoking subsolidus cooling can reconcile these high pressures with significant spinel formation by allowing more reaction in the spinel stability field on the isobaric, subsolidus cooling path. This higher pressure is further substantiated by the greater jadeite content in corona clinopyroxene.

Quantitative P,T estimates from the coronite mineralogy have proved to be ambiguous although two of the most unevolved samples do give the estimates of 9-10 Kbars. The graphical pyroxene highest pressure thermometer of Lindsley & Anderson (1983) produces a range of temperature estimates between 950 and 750°C and if real, these may be compatible with "frozen" Ca-distribution during subsolidus cooling. Moreover as the graphical thermometer produces comparable "metamorphic" results to garnetclinopyroxene thermometry in both recrystallised metagabbros and host (700-750°C, section 5.4.2), Ca redistribution by volume granulites diffusion may close at higher temperatures that Fe-Mg exchange because temperature estimates in coronites from garnet-clinopyroxene and garnetthermometry are normally indistinguishable from those orthopyroxene obtained in the host rocks. Thus although the coronites represent textural

disequilibrium the cation distributions have apparently re-equilibrated, at least in terms of Fe and Mg, by continuous reactions during the subsequent evolution. If this is the case the metagabbros provide an independant test on the reliability of barometry in assemblages from the host rocks and taken together they imply metamorphism at 8-10 Kbars and 700-750°C. Furthermore both suggest slightly lower pressure in the Opeongo and Kawagama areas.

This Chapter considered how changing physical conditions in the CGB influenced the textural evolution of metagabbros after their intrusion at around 1200 Ma. The next Chapter discusses the internally imposed controls on the early corona-forming reactions by examining mineral kinetics.

# CHAPTER VII

# DIFFUSION MODELS FOR CORONA FORMATION

# 7.1 INTRODUCTION

This Chapter presents a case study of internally imposed kinetic controls on metastable corona-forming reactions (Grant, in press). In equilibrium thermodynamics, the free energy change determines whether a reaction is feasible; i.e. -ve  $\Delta G$  for spontaneous change or  $\Delta G$  = 0 at equilibrium. Furthermore the favoured reacton is the one producing assemblages with minimum free energy. However, whether or not the reaction actually takes place depends on kinetics. Olivine corona reactions are solid=solid between anhydrous silicates and because a disordered fluid phase does not participate, they are likely to be accompanied by only small changes in entropy and free energy. Thus products forming by a mechanism involving minimum energy of activation result, rather than assemblages with minimum Free energy (Turner, 1981). This is known as Ostwald's Step Rule and has been invoked to explain such features as the growth of sillimanite in the kyanite stability field because sillimanite nucleates with lower  $\Delta S$  of activation.

In this Chapter irreversible thermodynamics have been used to model corona-forming reactions in terms of steady state diffusion where entropy production is minimised. The reactions probably took place during slow cooling from magmatic temperatures, although a prograde origin cannot be the subsolidus discounted irrespective of entirely. Nonetheless, mechanism, evidence presented in Chapter 6 favours a single-stage process for early reactions so that simplified models can be developed for diffusion-controlled growth. The only information required to make these model calculations is the mineral formulae of each phase involved. However the predicted layer sequences are only applicable if reactions took place in a steady state where local equilibrium was maintained across layer contacts. The consistent phase relations discussed in Chapter 6 suggest that the latter did indeed prevail, but a steady state can only be assumed and not proven. The externally imposed controls on reactions, including P,T and fluid composition were discussed in Chapters 5 & 6 and indicate

```
dc /dt: Rate of change in concentration.
d_S/dt: Rate of internal entropy production.
    \Delta S: Change in entropy.
   J_{-}^{R}: Rate of reaction r.
   J^{\dot{D}} : Rate of diffusion.
   A : Affinity for reaction r.
   J. : Flux of component i, superscript D omitted.
   µ: Chemical potential of component i.

abla \mu_i: Chemical potential gradient, 
abla - differential operator.
   v^n: Stoichiometric coefficient of component i at layer
         contact n.
   L_{i,i}: Phenomenological cross-coefficient for diffusion of
         component i in the µ-gradient of component j.
   L, : Diagonal or straight phenomenological coefficient for
         diffusion of component i in its own \mu-gradient.
   n_i \phi: Number of moles of component i in phase \phi.
   v\phi^n: Number of moles of phase \phi produced or consumed at layer
         contact n; n=1 -olivine interface, n=n -plagioclase
         interface.
    w,: Mobility of component i in the intergranular film.
 LMLF: L<sub>HaMa</sub> /L<sub>FeFe</sub>, ratio of straight L-coefficients.
 LMLS: L<sub>HaMa</sub>/L<sub>SiSi</sub>.
 LMLA: L<sub>HgHg</sub>/L<sub>AlAl</sub>.
 LMLC: L HgHg /L Cata
 LMLN: LHING /LNANA .
 LCLA: L /L /L /L /L /L /LMLC).LMLA
 LSLA: L<sub>SISI</sub>/L<sub>AIAI</sub> = (1/LMLS).LMLA
 LCLS: L<sub>LaCa</sub>/L<sub>SiSi</sub> = (1/LMLC).LMLS
LMLAS: LHBHS/LAISI(AISI).
LCMLC: L<sub>CaMg</sub> /L<sub>CaCa</sub>, ratio of cross-coefficients.
LCFLC: L /L Cata.
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pressures of 8-10 Kbars and minimum temperatures of 700-750°C under reduced, but variable water activity. The thermodynamic abbreviations employed in this Chapter are given in Table 7.1.

## 7.2 MINERAL CHEMISTRY

The reactions between olivine and plagioclase resulted in the variety of zonal mineral sequences discussed in Chapter 6. The two samples selected for detailed modelling consist of an opx-cpx-amph-(amph-gt) symplectite assemblage (Plate 6.1a) and the more common opx-cpx-(cpx-gt) corona (Plate 6.1b-c). They both come from the same gabbro body, 1-1.5 km in largest dimension, at Moore Point in Go Home subdomain (Fig. 3.2) on the shores of Georgian Bay (Davidson et al., 1985). Representative mineral compositions are presented graphically in Figure 7.1 and given in Appendix III.

### Primary Phases

Olivine composition varies within the gabbro body from  $Fo_{53} - Fo_{62}$ . Spinel-clouded plagioclase has a remarkably constant composition around  $An_{38-40}$  where spinel inclusions contribute 3-4 wt% Mg, Fe to the bulk analyses. This is consistent with results obtained by Whitney & McLelland (1973) and McLelland & Whitney (1980) for similar coronite metagabbros in the Adirondacks, New York State. Recalculated primary pyroxene compositions are represented by Wo<sub>39</sub> En<sub>38</sub> Fs<sub>10</sub> Jd<sub>7</sub> TiTs (CaFeTs in DMS-8 and Wo<sub>37</sub> En<sub>36</sub> FS<sub>10</sub> Jd<sub>8</sub> TiTs (CaFeTs CaTs, in DMS-13A.

### Corona Orthopyroxene

Orthopyroxene is radially orientated around the olivine core and the only variation across the layer is in Wt/  $Al_2O_3$ ; 1.4-1.9 wt/ in DMS-8 and 0.8-1.3 in DMS-13A where less aluminous compositions occur adjacent to olivine. Calcium contents are very low and neglected in the modelling, resulting in the simplified compositions of En\_{68}Fs\_{32} in DMS-8 and En\_{65}Fs\_{35} in DMS-13A, although the latter is slightly more calcic than in DMS-8.

### Corona Clinopyroxene

As in orthopyroxene Wt% Al $_{20}^{0}$  varies across the layer and contributes 2-3.5 wt% in DMS-13A and 3-3.5 wt% in DMS-8. In terms of recalculated components, the average clinopyroxene in DMS-8 is Wo<sub>40</sub> En<sub>38</sub> Fs<sub>11</sub> Jd<sub>8</sub>

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FIGURE 7.22 & b: Cation ratios obtained from 50x50  $\mu$ m area scans of symplectites and spinel-clouded plagioclase in DMS-8 and DMS-13a. Also plotted are the average results ( $\Delta$ ) for symplectites from other coronite bodies in the CGB, and point analyses of corona amphibole, garnet and clinopyroxene. The corresponding ratios in various hypothetical plagioclase compositions are plotted for comparison.



CaFeTs, CaTs, and Wo, En, 7Fs, 0Jd, CaFeTs, CaTs, in DMS-13A.

### Amphibole

This is present in the olivine coronas from sample DMS-13A and is a pargasite (Leake, 1978). It is pale green and has a more variable composition than the adjacent pyroxenes, especially in the  $Al_2O_3$  and  $SiO_2$  contents which vary by  $\pm 2$  Wt<sup>2</sup>.

### Bulk Symplectite

The bulk composition from 50 x 50 µm area scans were discussed at length in Chapter 6, section 6.4.1 and the proposed mean compositions are used as major constraints in the diffusion models which follow. Figure 7.2 presents microprobe analyses from DMS-8 and DMS-13A in terms of cation ratios and should be compared with the average symplectite composition of several other gabbro samples from the Central Gneiss Belt (CGB) ( $\Delta$  in Figs. 7.2 and 6.4). The main difference between the samples is the greater proportion of CaO and lesser Na<sub>2</sub>O in DMS-8 because clinopyroxene rather than amphibole, is the other symplectite phase. The proportion of garnet relative to amphibole or clinopyroxene has been calculated from the average bulk composition using a weighted least-squares approximation. This resulted in X  $\approx 0.2$  in sample DMS-13A and X  $\approx 0.25$  in DMS-8, when a 'best fit' for all components is applied.

### Garnet

Narrow, discontinuous garnet rims are more iron-rich in DMS-13A and the recalculated composition is  $\operatorname{And}_{1}\operatorname{Py}_{27}\operatorname{Sp}_{2}\operatorname{Gr}_{17}\operatorname{Alm}_{53}$  compared with  $\operatorname{And}_{1}\operatorname{Py}_{32}\operatorname{Sp}_{1}\operatorname{Gr}_{16}\operatorname{Alm}_{50}$  in DMS-8. In the following diffusion models, the garnet layer is neglected because it is not continuous and is unevenly and preferentially developed adjacent to the most intensely clouded plagioclase.

## **7.3 THE KINETICS OF CORONA FORMATION**

The kinetics of corona-forming reactions are determined by two factors (Fisher, 1977):

(i) Diffusion of components between two reactants where the

diffusive flux of the slowest moving species is rate-determining.

(ii) The rate of reaction  $(J_r)$  at each interface. This depends on the

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interface mechanism and is a function of the affinity for reaction  $\binom{A}{r}$ , which is the difference between the chemical potential of diffusing components and their equilibrium values (at A = 0). These are

linked by the conservation equation:  $dc_i/dt = -dJ_i^0/dx + \Sigma v_i J_r^R$ - where superscripts D and R correspond to the rates of diffusion and reaction respectively. This equation represents the change in concentration at a reaction interface, of a given component (i), that results from the difference between its rate of production and its net loss by diffusion. It is the slower of these two processes that determines the rate of consumption or production of the component in an exchange cycle and hence controls the overall rate of reaction. In the case of coronas presented here, textural evidence suggests early, single-stage corona growth where diffusion was rate-controlling for several reasons:

- a) The degree of spatial organisation in the coronas. If the diffusion coefficients were large and not rate-determining, chemical potential gradients would be virtually eliminated. As a result the potential differences would tend to be uniform over a large rock volume and nucleation could occur at any suitable low energy sites, while dissolution would be widespread (Fisher 1977). The overall rate of reaction then becomes a function of the rates of local chemical reactions, driven by only very small differences in the chemical potential gradients.
- b) The proportion of aluminium decreases in step-like fashion across the corona assemblage (Fig. 7.1) and steadily within the clinopyroxene and symplectite layers, suggesting aluminium may be much less mobile and this may be rate-limiting during corona growth.
- c) The significance of a symplectite in corona-forming reactions was noted by Mongkoltip & Ashworth (1983). They attribute its formation to a mechanism analogous to a duplex cell, which is limited only by grain boundary diffusion and develops by a form of exsolution, or eutectoid reaction (Yund & McCallister 1970). Like other corona reactions this takes place along an incoherent interface which is advancing into fresh matrix, so again there is no need to invoke long range diffusion. In the CGB, the Al:Si ratio of the symplectite varies across the layer from values equivalent to an Al-Si framework in plagioclase, ranging in composition from An<sub>32</sub> to An<sub>55</sub> (Figs. 7.2 & 6.4); in thin section this is shown by the greater concentration of cpx, hence lower Al/Si in the

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symplectite immediately adjacent to clinopyroxene, compared with the centre of the symplectite. This suggests that restricted mobility of Al,Si from plagioclase may have been important for corona growth. A similar feature is noted in other corona sequences where discontinuous orthopyroxene-garnet symplectites formed between olivine and a plagioclase moat. This plagioclase is more sodic  $(An_{24-28})$  than matrix plagioclase  $(An_{40-41})$  and the Al:Si ratio of 0.44 is again analogous to the bulk (opx-gt) symplectite. This is an unlikely coincidence and it appears that the Al:Si ratio in adjacent plagioclase does influence the bulk symplectite composition. This proposal was also made by Mongkoltip & Ashworth (1983) for amphibole-spinel symplecites adjacent to calcic plagioclase in coronas from the Newer Basic intrusions of NE Scotland. Here the Al:Si in the symplectite ranges from 0.66 to 0.81 and this varies sympathetically with adjacent plagioclase  $(An_{68-79})$ , corresponding to Al:Si ratios of 0.72 to 0.81.

d) If the reaction rate had been determined by the nucleation/growth of garnet, or dissolution of plagioclase, no symplectite would form; silica would have sufficient time to diffuse away from the plagioclase interface with a consequent increase in Al/Si, allowing monomineralic garnet layers to dominate and grow at the expense of a symplectite layer. However aluminium has lower mobility because of the greater proportion of garnet in the symplectite adjacent to plagioclase and the common observation of a very narrow, discontinuous garnet layer adjacent to the most intensely spinel-clouded, and hence most aluminous plagioclase.

These observations led to the following attempts to model disequilibrium corona sequences using the irreversible thermodynamic models developed by Fisher (1973, 1977), Joesten (1977). Foster (1981) and applied to olivine coronas by Nishiyama (1983) and Joesten (1985, 1986a). Nishiyama (1983) found that the relative mobility of Mg and Al had the most influence on the stability of a cumm-(hbl+sp) corona under isobaric, isothermal conditions, while Joesten (1986a & b) demonstrated that a corona comprising two adjacent symplectite layers was diffusionally unstable.

In simple component terms Fe,Mg diffused down  $\mu$ -gradients between olivine and plagioclase while the other major components Al,Ca,Si,Na diffused towards olivine during corona growth. The reactions were favoured at zone boundaries where the structural disorder is greatest and chemicalpotential gradients change most rapidly. This resulted in the spatial

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zonation of coronas and leads to a simplifying assumption that no dissolution or precipitation occurs within the layers and the following models solve for reaction at layer contacts only. The aim of the modelling was to estimate the relative values of the phenomenological or Onsager coefficients for diffusion  $\{L_{ij}\}$ , using observed modal mineral proportions as constraints on the solutions. The L-coefficients are analogous to the experimentally determined diffusion coefficients (D), but have the advantage of relating diffusion to chemical potential rather than concentration gradients. The former easier to evaluate thermodynamically from the Gibbs-Duhem equations, using mineral compositions from microprobe analyses.

A major simplifying assumption is that the corona reactions occur in the steady state where the forces, or chemical potentials in this case, are constant. The chemical potentials (µ) will remain fixed if the stoichiometry of the reactions balance the net flux by diffusion; any material flow due to unfixed forces increasing the concentration of that component in the intergranular film, thus promoting rapid reaction to remove the perturbation and restoring the steady-state potentials. The steady state minimises entropy production (Katchalsky and Curran 1965) and leads to the metastable existence of coronas at an energy low. Additional energy input is required to overcome activation energy barriers to further reaction and eventual equilibration. The trend toward minimum entropy production represents the tendency of a system to approach as closely as possible the reversible state (Fisher 1973). Consequently the system is not far from equilibrium and all higher order terms in a series relating the flux J, of a component to the applied forces can be ignored, leaving an approximately linear relationship between forces and fluxes.

Growth of coronas will slow and eventually stop when the diffusion paths become too long and the µ-gradients too low to drive significant diffusion. In addition the absolute values of the diffusion coefficients vary exponentially with temperature. As a result a drop in temperature inhibits diffusion and may be important for stopping corona growth and allowing coronas to persist metastably during subsolidus cooling from magmatic temperatures. However, in the models, it is assumed that the ratios of diffusion coefficients are approximately constant over the unknown temperature interval of corona growth. The kinetic factors that influenced the subsequent textural evolution were discussed in Chapter 6 and reflect slow nucleation/growth of garnet where the rate was probably

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contolled by the interface mechanism, rather than component diffusion.

### 7.3.1 STEADY STATE DIFFUSION MODEL

This section is a summary of the irreversible thermodynamic models developed by Fisher (1973), Joesten (1977) and applied to natural examples by Joesten (1978,1986a), Nishiyama (1983) and Foster (1981).

1) Internal entropy production is a function of rate terms and applied forces such as heat or chemical potential:

$$d_{i}S/dt = \sum J_{i}X_{i} \ge 0 \dots (1.1)$$

 $X_k$  is the force;  $J_k$  the rate term for diffusion or reaction,  $J^0$  or  $J^R$  (hereafter the superscripts R and D are omitted and all J terms apply to diffusive fluxes unless otherwise stated). There may be a number of applied forces and each contributes to the net entropy production. Near equilibrium there is an approximately linear relationship between the force (µ-gradient in this case) and the flux J, it produces:

$$J_{i} = \Sigma_{j=1}^{n} L_{ij} X_{j}$$
 .....(1.2)

2) The flux (J<sub>i</sub>) is related to the chemical potential gradient (d $\mu$ /dx) by the Onsager coefficients for diffusion (L<sub>ii</sub>).

e.g.  $J_1 = L_{11}d(-\mu_1)/dx + L_{12}d(-\mu_2)/dx + \dots etc.$  (1.3)

The flux J must be measured with respect to a particular frame of reference, whereas the  $\mu$ -gradient is independent of the reference frame (Brady 1975). In the models developed here a layer-contact fixed frame is adopted after Joesten(1977) and Nishiyama (1983).

3) The rate of diffusion for n-components is given by a set of n linear equations in the generalised form of (1.3) by

 $J_i = L_{i1} \nabla \mu_1 + L_{i2} \nabla \mu_2 + \dots + L_{in} \nabla \mu_n$ , or in matrix form:

$$\begin{vmatrix} L_{11} & L_{12} & \cdots & L_{1n} \\ L_{21} & L_{22} & \cdots & L_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ L_{n1} & L_{n2} & \cdots & L_{nn} \end{vmatrix} \quad \begin{bmatrix} \nabla \mu_1 \\ \nabla \mu_2 \\ \cdots \\ \nabla \mu_n \\ \nabla \mu_n \\ \end{bmatrix} \quad \begin{bmatrix} J_1 \\ J_2 \\ \cdots \\ J_n \\ \cdots \\ \end{bmatrix}$$

This gives rise to  $(n)^2$  L-coefficients for an n-component system. However, Onsager in 1931 demonstrated the symmetry of the matrix of phenomenological coefficients (Onsager's Reciprocal Relation) such that  $L_{ij} = L_{ji}$ , and this greatly reduces the number of independent unknowns.

4) The  $L_{ii}$  are always positive and the square of the cross-coefficient term is always less than the product of the corresponding diagonal coefficients; i.e.  $L_{ii}L_{jj} > (L_{ij})^2$  (Katchalsky & Curran 1965). Thus the straight coefficients  $(L_{ii})$  dominate the flux equation leading to the useful approximation:  $J_i = L_{ii}d(-\mu_i)/dx$  .....(1.4)

Individual L are functions of concentration through the equation  $L_{ii} = C_{iw}$ , but the ratios of L-coefficients are independent of concentration (Nishiyama, 1983) and are assumed to be constant across the corona.

5) Possibility of "uphill diffusion" if  $\Sigma_{j=1}^{n} L_{ij} d(-\mu_{j})/d(-\mu_{j}) > L_{ii} \dots (2)$ 

This is likely if component i has low mobility or concentration in its own  $\mu$ -gradient, but has an effective flux by diffusing up the  $\mu$ gradients of components j,k etc. The importance of this for Cadiffusion is demonstrated in Figure 7.3 where variables for uphill diffusion of Ca in the  $\mu$ -gradients of Mg and Fe are included (discussed later).

5) To set up the steady diffusion model it is necessary to solve simultaneously the following three sets of linear equations (Joesten, 1977):

(i) Mass Balance:  $v_i^n = \Sigma v_{\phi}^n n_i \phi$  .....(3)

e.g. Mg\_SiO, /MgSiO, (Fo/En contact)

 $v_{Mg} + 2v_{01} + v_{0px} = 0$  &  $v_{Si} + v_{01} + v_{0px} = 0$ 

....leads to constant overall proportions of minerals for a given set of mass balance equations used in modelling the corona.

(ii) Conservation equations:  $V_i = j^{n/eut} - j^{n/in} \dots (4a)$ , and  $j^{n/in} = j^{(n-1)/eut} \dots (4b)$  This, coupled with a closed system assumption involving no diffusion of components into either olivine or plagioclase, leads to one conservation equation for each component across all layer contacts. e.g. for Mg,  $v_{\text{Mg}}^{1} + v_{\text{Mg}}^{2} + v_{\text{Mg}}^{3} + \dots v_{\text{Mg}}^{n} = 0$  ...(4c)

(superscripts 1,2 etc. refer to each reaction interface)

- (iii) Flux ratio equations: these control individual layercontact reactions and depend on the relative mobility of components in the form of ratios of the L-coefficients. The time dependence of  $\mu$ -gradients in the flux equations(1.3) is removed by taking their ratio and applying the Gibbs-Duhem equation for local equilibrium at layer contacts, i.e.  $\sum n_i d\mu_i = 0$  ..(5.1)
  - e.g. flux ratio eqn for an enstatite layer: From (1.3)  $J_{c_1}^{-1} = L_{c_1c_1} d(-\mu_{c_1})/dx$

$$J_{Hg}^{1} = L_{HgHg} d(-\mu_{Hg})/dx$$

Rearranging  $d\mu_{Si}/dx = -J_{Si}^{1}/L_{SiSi}$  and  $d\mu_{Hg}/dx = -J_{Hg}^{1}/L_{HgHg}$  ..(5.2)

Applying Gibbs-Duhem eqn.,  $1d\mu_{Si}/dx + 1d\mu_{H_0}/dx = 0$  (5.3)

Replacing the fluxes by stoichiometric coefficients for components at the reaction interface and combining (5.2) and (5.3):  $v_{Ha}^{1} + (L_{HaHa}/L_{SiSi})v_{Si}^{1} = 0$  ....(5.4)

### 7.4 APPLICATION OF DIFFUSION MODELS TO CORONA FORMATION.

Two coronas have been modelled in the CMAS, FCMAS and NFCMAS systems and by varying the concentration and mobility of components, it is possible to generate different sequences and proportions of stable mineral assemblages. Both samples come from the same gabbro body, so nearly identical pressure and temperature conditions apply, although fluid

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activity may have varied throughout the intrusion. In the model sequence only one layer can grow by reaction at both contacts and this must contain the initial contact between reactant phases. No layer can be eliminated by diffusion once the steady state is established. The simple CMAS system is inadequate because Mg/Fe varies across the corona, reaching a maximum in clinopyroxene (Figs. 7.1 & 5.5a). This variation is the result of local equilibrium partitioning of Mg,Fe by the FeMg\_1 exchange vector and although important for overall mass balance of the coronas, it is relatively rapid and not rate-determining in the corona formation.

A major restriction on the models comes from volume estimates of corona proportions. This was discussed in Chapter 6, section 6.4.3 where results are presented in Table 6.7. These are compared with model proportions in Table 7.2 (columns 4-6) which were obtained from application of the mass balance equations described above to the two samples discussed here.

In the model the assumption of a closed system (eqn. 4c) implies there is no diffusion away from the reaction interface into olivine or plagioclase. This breaks down because Mg, Fe must leave the olivine corona to form spinel-clouding in plagioclase but is neglected in the modelling as both are likely to be relatively mobile compared with other components. However, no plagioclase composition, including end-member anorthite, can liberate enough calcium to produce the observed mineral proportions. To overcome this apparent contradiction, a "closed system" ratio of Si:Al: Ca:Na has to be adopted. It represents the net result of several exchange reactions within plagioclase laths, involving the continued development of spinel clouding in the early stages of reaction. accompanied by a transformation to more sodic compositions, thereby liberating additional Ca for corona formation. The reactant Al:Ca ratio can be extracted from the observed mineral proportions as both components are derived from the plagioclase interface. However determining Al:Si in the reactant is a major problem and several closed system ratios have been tested. Some results of this are presented in Table 7.2, columns 4-6. The Anga Al:Si ratio of 0.53 is the maximum obtained for clear plagioclase lath margins and is a minimum reactant ratio because a symplectite is commonly not produced adjacent to more sodic plagioclase. The Al:Si=0.61 corresponds to integrated ratio from area scans of heavily spinel-clouded the plagioclase. This is "PLAG2" in Table 7.3 and the Al:Si is equivalent to An<sub>50-55</sub> (Fig. 7.2), but the calcium content corresponds to An<sub>38</sub>. It

Table 7.2: Estimated proportions of corona minerals compared with the model molar proportions obtained from various Al/Si ratios in a plagioclase framework. The volumes were calculated by assuming a spherical corona and converted to molar proportions using the molar volume data of Robie et al. (1981).

DMS-8	OBSERVED I	MINERAL PROPO	MODEL MOLAR PROPORTION						
			TOTAL	An38	"PLAG1"	"PLAG2"			
	VUL PRUPS	MULAR PRUPS	GT, CPX	A1/Si=.53	0.55	0.61			
OPX	0.23	0.30		0.39	0.37	0.31			
CPX	0.20	0.26	0.34	0.27	0.30	0.32			
SYM	0.57	0.44	-	-	-	-			
GT	-	-	0.37	0.32	0.33	0.36			
DMS-13A		* * * * * * * * * * * * * * *							
OPX	0.23	0.38	TOTAL	0.42	0.39	0.27			
CPX	0.12	0.20	GT.AMP	0.18	0.18	0.18			
AMPH	0.26	0.10	0.14	0.13	0.15	0.22			
SYM	0.26	0.20	-	-	-	-			
GT	0.13	0.11	0.27	0.28	0.29	0.33			

TABLE 7.3: Mineral phases in terms of simple oxide components

DMS-8	MgO	FeO	Si0 <sub>2</sub>	A10 <sub>3/2</sub>	CaO	Na0 1/2
OL	1.20	0.80	1.00		-	-
OPX	1.36	0.64	1.96	0.07	-	-
СРХ	0.75	0.23	1.95	0.15	0.85	0.08
GT	0.95	1.50	3.00	2.00	0.55	-
SYM	1.10	1.36	3.13	1.72	0.70	0.02
An <sub>a e</sub>	-	-	10.50	5.48	1.54	2.40
"PLAG1"	-	-	3.09	1.70	1.00	0.40
"PLAG2"	_	-	2.79	1.70	1.00	0.40
DMS-13A						
OL	1.10	0.9	1.00			-
OPX	1.30	0.70	1.98	0.05	-	-
CPX	0.75	0.23	1.96	0.15	0.85	0.08
AMPH	2.90	1.40	6.20	2.60	1.80	0.90
GT	0.86	1.60	3.00	2.00	0.54	-
SYM	1.00	1.40	3.14	1.74	0.67	0.08
			~ ~			

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represents the maximum reactant A1:Si because a narrow garnet layer is commonly generated in the adjacent corona, whereas a symplectite occurs next to clear lath margins and less clouded plagioclase (Plate. 6.1a). This ratio probably represents the primary plagioclase composition and is supported by whole rock normative values of  $An_{SO-GO}$  (Fig. 4.1a). The retention of the original A1:Si reflects the low mobility of A1,Si from the earliest stages of olivine-plagioclase instability, when the initial flux of calcium left excess aluminium. This, coupled with the complementary flux of Mg,Fe from olivine, resulted in the exsolution of spinel. If this is correct, the initial instability of olivineplagioclase, possibility as the rocks moved rapidly through the spinel field, may have promoted the steady state fluxes responsible for the observed corona mineralogy in the garnet stability field; continued corona growth requiring a calcium flux from more distant plagioclase, until it all adopted an  $An_{2n-i4}$ , composition.

A compromise reactant ratio is provided by Al:Si=0.55. "PLAG1" in Tables 7.2 & 7.3. This is equivalent to the mean symplectite Al:Si ratio (Fig. 7.2) and a plagioclase around  $An_{42-44}$ . It reflects the assumption that the flux of Al,Si from plagioclase was a major constraint on the symplectite composition. This was tested in Chapter 6, section 6.7 using the method in Gresens (1967) where it was found that  $An_{46}$  and the mean symplectite composition conserved Al,Si at the plagioclase interface at under approximately constant volume replacement (Fig. 6.17e & f).

The average symplectite and the aluminous primary Al;Si ratios result in two limiting "closed system ratios" of 3.09:1.7:1:0.4 ("PLAG1") and 2.79:1.7:1:0.4 ("PLAG2") respectively. Both have been used in the models and the results are presented in the L-ratio diagrams (Figs. 7.4 & 7.5) to show the effect of reactant Al:Si on the position of contours for  $X_{fit}^{Sym}$ .

Some simplified results from modelling the opx-cpx-amph-(amph-gt) corona in the NFCMAS system are presented in Figure 7.3. The simple oxide components, neglecting MnO,  $K_2O$  and TiO<sub>2</sub>, are listed in Table 7.3 and result in the set of simultaneous equations given in Table 7.4. In the calculations the flux of magnesium evolving from the olivine interface,  $v^1_{Mg}$ , is set arbitrarily to two. Mass balance requires constant overall proportions of phases, but varying the ratio of Onsager coefficients (L<sub>ii</sub>) in the flux-ratio equations (6a-6e) results in different stoichiometries of layer contact reactions and varying proportions of amphibole and garnet

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FIGURE 7.3a: Simple oxide model showing the influence of relative Al-mobility on the stability of the amphibole-bearing corona assemblage. Constructed using "PLAG1" and diagonal L-coefficients ratios only. <u>3b</u>: The effect of including cross-coefficient ratios of LCMLC, LCFLC = -0.4 in the preceding model. <u>3c</u>: Varying cross-coefficient ratios at fixed values of diagonal L-coefficient ratios; i.e LMLF, LMLS, LMLA, LMLC, LMLN=1,3,10,2,1 respectively.



TABLE 7.4: Steady state equations describing the corona in DMS-13A; an opx-cpx-amph-(amph-gt)sym corona.

(i) Mass Balance equations

Olivine-Orthopyroxene layer contact (1)

$$v_{Hg}^{1} + 1.1v_{01}^{1} + 1.3v_{0px}^{1} = 0, \quad v_{Fe}^{1} + .9v_{01}^{1} + .7v_{0px}^{1} = 0$$
  
$$v_{Si}^{1} + v_{0i}^{1} + 1.98v_{0px}^{1} = 0, \quad v_{Ai}^{1} + .05v_{0px}^{1} = 0$$

Orthopyroxene-Clinopyroxene contact (2)

$$v_{Hg}^{2} + 1.3v_{0px}^{2} + .75v_{0px}^{2} = 0, v_{Fe}^{2} + .7v_{0px}^{2} + .23v_{0px}^{2} = 0$$

$$v_{Si}^{2} + 1.98v_{0px}^{2} + 1.96v_{0px}^{2} = 0, v_{A1}^{2} + .05v_{0px}^{2} + .15v_{0px}^{2} = 0$$

$$v_{Ca}^{2} + .85v_{0px}^{2} = 0, v_{Na}^{2} + .08v_{0px}^{2} = 0$$

Clinopyroxene-Amphibole layer contact (3)

$$v_{\text{Hg}}^{3} + .75v_{\text{Cpx}}^{3} + 2.9v_{\text{Amp}}^{3} = 0, \quad v_{\text{Fe}}^{3} + .23v_{\text{Cpx}}^{3} + 1.4v_{\text{Amp}}^{3} = 0$$

$$v_{\text{Si}}^{3} + 1.96v_{\text{Cpx}}^{3} + 6.2v_{\text{Amp}}^{3} = 0, \quad v_{\text{Al}}^{3} + .15v_{\text{Cpx}}^{3} + 2.6v_{\text{Amp}}^{3} = 0$$

$$v_{\text{Ca}}^{3} + .85v_{\text{Cpx}}^{3} + 1.8v_{\text{Amp}}^{3} = 0, \quad v_{\text{Na}}^{3} + .08v_{\text{Cpx}}^{3} + .9v_{\text{Amp}}^{3} = 0$$

Amphibole-Symplectite layer contact (4)

$$v_{Hg}^{4} + 2.9v_{Amp}^{4} + .86v_{Gt}^{4} = 0, \quad v_{Fe}^{4} + 1.4v_{Amp}^{4} + 1.6v_{Gt}^{4} = 0$$

$$v_{S1}^{4} + 6.2v_{Amp}^{4} + 3v_{Gt}^{4} = 0, \quad v_{A1}^{4} + 2.6v_{Amp}^{4} + 2v_{Gt}^{4} = 0$$

$$v_{Ca}^{4} + 1.8v_{Amp}^{4} + .54v_{Gt}^{4} = 0, \quad v_{Na}^{4} + .9v_{Amp}^{4} = 0$$

Symplectite-("PLAG1") layer contact (5)

$$v_{Hg}^{5} + 2.9v_{Anp}^{5} + .86v_{Gt}^{5} = 0, v_{Fe}^{5} + 1.4v_{Anp}^{5} + 1.6v_{Gt}^{5} = 0$$

$$v_{Si}^{5} + 6.2v_{Anp}^{5} + 3.0v_{Gt}^{5} + 3.09v_{P1}^{5} = 0,$$

$$v_{A1}^{5} + 6.2v_{Anp}^{5} + 2v_{Gt}^{5} + 1.7v_{P1}^{5} = 0,$$

$$v_{Ca}^{5} + 1.8v_{Anp}^{5} + .54v_{Gt}^{5} + v_{P1}^{5} = 0,$$

$$v_{Na}^{5} + .9v_{Anp}^{5} + .4v_{P1}^{5} = 0$$

(ii) Conservation equations:

$$v_{H_{g}}^{1} + v_{H_{g}}^{2} + v_{H_{g}}^{3} + v_{H_{g}}^{4} + v_{H_{g}}^{5} = 0$$

$$v_{F_{e}}^{1} + v_{F_{e}}^{2} + v_{F_{s}}^{3} + v_{F_{s}}^{4} + v_{F_{e}}^{5} = 0$$

$$v_{S1}^{1} + v_{S1}^{2} + v_{S1}^{3} + v_{S1}^{4} + v_{S1}^{5} = 0$$

$$v_{L_{a}}^{1} + v_{A1}^{2} + v_{A1}^{3} + v_{A1}^{4} + v_{A1}^{5} = 0$$

$$v_{L_{a}}^{2} + v_{L_{a}}^{3} + v_{L_{a}}^{4} + v_{L_{a}}^{5} = 0$$
(iii) Flux ratio equations:
$$1.3v_{H_{g}}^{1} + .7LMLFv_{F_{e}}^{1} + 2LMLSv_{S1}^{1} + .05LMLAv_{A1}^{1} = 0 \dots (6a)$$

$$.75(v_{H_{g}}^{1} + v_{H_{g}}^{2}) + .23LMLF(v_{F_{e}}^{1} + v_{F_{e}}^{2}) + 1.96LMLS(v_{S1}^{1} + v_{S1}^{2})$$

$$+ .15LMLA(v_{A1}^{1} + v_{A1}^{2}) + .65LMLCv_{L_{a}}^{2} + .08LMLNv_{N_{a}}^{2} = 0 \dots (6b)$$

$$2.9(v_{H_{g}}^{4} + v_{H_{g}}^{5}) + 1.4LMLF(v_{F_{e}}^{4} + v_{F_{e}}^{5}) + 6.2LMLS(v_{S1}^{4} + v_{S1}^{5})$$

$$+ 2.6LMLA(v_{A1}^{4} + v_{A1}^{3}) + 1.8LMLC(v_{L_{a}}^{4} + v_{L_{a}}^{5}) + ....(6c)$$

$$2.9v_{H_{g}}^{5} + 1.4LMLFv_{F_{e}}^{5} + 6.2LMLSv_{S1}^{5} + 2.6LMLAv_{A1}^{5} + 1.8LMLCv_{L_{a}}^{5} + ....(6c)$$

$$.86v_{H_{g}}^{5}$$
 + 1.6LMLFv<sub>Fe</sub><sup>5</sup> + 3LMLSv<sub>S1</sub><sup>5</sup> + 2LMLAv<sub>A1</sub><sup>5</sup> + .54LMLCv<sub>Ca</sub><sup>5</sup> = 0 .(6e)

(iv) Solve by setting  $v_{\text{Hg}}^1 \approx 2.0$ 

in the symplectite. Figure 7.3 demonstrates that decreasing aluminium mobility increases the proportion of garnet in the symplectite layer, but note this is a simple 1-dimensional case where all the other independent L-ratios are fixed at one, i.e. at equivalent mobility. The main constraint on the model solutions is the mean obtained from microprobe area scans of the symplectites that suggest the mole fraction of garnet,  $X_{Gt}^{Sym}$ , is approximately 0.80. This can only be obtained with difficulty for "PLAG2", and not at all with the less aluminous "PLAG1" composition. To increase the amount of a monomineralic amphibole layer it is necessary to consider other possible variables in the system. These include the effects of minor components and those arising from possible "uphill" diffusion.

### 7.4.1 THE EFFECT OF CROSS-COEFFICIENTS

Uphill diffusion has been demonstrated experimentally in relatively simple systems. In natural rock occurrences, Burt (1974) invoked the possibility of uphill Si-diffusion to explain metasomatic zoning in exoskarns, but ignored the effect of local equilibrium (Joesten pers. comm.). In this section a simplified model is developed to approximate more complicated interactions between diffusing species by modifying the preceding system of equations to take into account the effects of "uphill" Ca-diffusion. This calls for calcium evolving from the plagioclase interface, to diffuse up its own chemical potential gradient. The resulting cross-coefficient terms may be positive or negative, depending on whether the component is diffusing up or down the µ-gradients of other diffusing species. In this case it is proposed that calcium is diffusing up the  $\mu$ -gradients of Mg,Fe and vice versa, resulting in negative crosscoefficient terms. Thus uphill diffusion contributes negative terms to the entropy production equation (1.1), but it presents no problem thermodynamically, provided the overall entropy change is still positive and at • minimum. It favours an increase in  $J_{r_{a}}$  at the sym/cpx or amph/cpx layer contact and allows a greater proportion of the more calcic phase, clinopyroxene or amphibole, to form well within the corona sequence. The following section shows how including variables for "uphill diffusion" affect results from the diffusion models and demonstrates that it may contribute to the minimisation of entropy in the steady state exchange cycle.

The method involves substituting cross-coefficient terms, into the flux ratio equations (6a-e), under the following constraints:

- a) Diagonal or straight coefficients are always positive (Katchalsky & Curran 1965).
- b) Cross-coefficients may be positive or negative and
  - $L_{ii}L_{jj} > L_{ij}^2$ .
- c) Uphill diffusion when  $L_{ii} < \Sigma_{j=1}^{n} L_{ij} (\partial \mu_{j} / \partial \mu_{i})$  (Cooper 1974). d) Onsagers Reciprocal relation  $L_{ii} = L_{1i}$ .

e.g. Modified flux equation for the clinopyroxene layer. From equation (1.3):

$$J^{2}_{Ca} = L_{CaCa} d(-\mu_{Ca})/dx + L_{CaHg} d(-\mu_{Hg})/dx + L_{CaFe} d(-\mu_{Fe})/dx (7.1)$$

$$J^{2}_{Hg} = L_{HgHg} d(-\mu_{Hg})/dx + L_{HgCa} d(-\mu_{Ca})/dx \dots (7.2a)$$

$$J^{2}_{Fe} = L_{FeFe} d(-\mu_{Fe})/dx + L_{FeCa} d(-\mu_{Ca})/dx \dots (7.2b)$$

From eqns. (7.2a & b):  $d(-\mu_{Hg})/dx \pm J^2 / L_{HgHg} - L_{CaHg}/L_{HgHg} (d(-\mu_{Ca})/dx) ...(7.3a)$ 

$$d(-\mu_{Fe})/dx = J^{2}_{Fe}/L_{FeFe} - L_{FeCa}/L_{FeFe} (d(-\mu_{Ca})/dx) \dots (7.3b)$$

Substituting into eqn (7.1)  

$$J^{2}_{Ca} = L_{CaCa} d(-\mu_{Ca})/dx + L_{CaHg} (J^{2}_{Hg}/L_{HgHg} + L_{CaHg}/L_{HgHg} (-\mu_{Ca})/dx)$$

$$+ L_{CaFe} (J^{2}_{Fe}/L_{FeFe} + L_{CaFe}/L_{FeFe} d(-\mu_{Ca})/dx)$$

Rearranging

$$\frac{d(-\mu_{Ca})/dx = 1/L_{CaCa} (J^{2}_{Ca} - (L_{CaHg}/L_{HgHg})J^{2}_{Hg} - (L_{CaFe}/L_{FeFe})J^{2}_{Fe})}{(1 - (L_{CaHg})^{2}/L_{CaCa}L_{HgHg} - (L_{CaFe})^{2}/L_{CaCa}L_{FeFe}]}$$

Replacing fluxes by stoichiometric coefficients and using the following abbreviation for the denominator:

$$Y = [1 - (L_{CaHg})^2 / L_{CaCa} L_{HgHg} - (L_{CaFe})^2 / L_{CaCa} L_{FeFe}]$$

$$\frac{d(-\mu_{Ca})/dx = 1/L_{CaCa}[-(L_{CaHg}/L_{CaCa}.(L_{CaCa}/L_{HgHg}))(v_{Hg}^{1} + v_{Hg}^{2})}{(L_{CaFe}/L_{CaCa}.L_{CaCa}/L_{FeFe})(v_{Fe}^{1} + v_{Fe}^{2}) + v_{Ca}^{2}]/Y} \dots (7.4)$$

Similarly for 
$$\nabla(-\mu_{Hg})$$
 and  $\nabla(-\mu_{Fe})$ :  $d(-\mu_{Hg})/dx = \frac{1}{L_{HgHg}} (v^{1}_{Hg}+v^{2}_{Hg}) - (L_{CaFe}/L_{CaCa})^{2} \cdot (L_{CaCa}/L_{FeFe}) \cdot (v^{1}_{Hg}+v^{2}_{Hg}) - \frac{L_{CaHg}/L_{CaCa}}{(v^{2}_{Ca}-L_{CaFe}/L_{CaCa})^{2} \cdot (L_{CaCa}/L_{FeFe}) \cdot (v^{1}_{Fe}+v^{2}_{Fe}) ]/ Y$ 

This is substituted into the flux ratio equations presented in Table 7.4, equations (6a) to (6e) for garnet, amphibole and clinopyroxene and results in the following modifications, using the abbreviations:

$$XFM = L_{CaHg} \cdot L_{CaFe} / (L_{CaCa})^{2}$$

$$XH = (L_{CaHg} / L_{CaCa})^{2}$$

$$XF = (L_{CaFe} / L_{CaCa})^{2}$$

$$A = L_{CaCa} / L_{FeFe} = (1/LMLC) \cdot LMLF$$

$$B = L_{CaCa} / L_{HgHg} = 1/LMLC$$

1) For Cpx, recall eqn (6b)  

$$.75d\mu_{Hg}/dx + .24d\mu_{Fe}/dx + 2d\mu_{Si}/dx + .14d\mu_{Al}/dx + .85d\mu_{Ca}/dx + .08d\mu_{Na}/dx = 0$$

+ 
$$(v_{Hg}^{1} + v_{Hg}^{2})[.75(1-XF.A) + .24(LMLF.XFM.B) - .85(LMLC.LCMLC.B)]/Y$$
  
+  $(v_{Fe}^{1} + v_{Fe}^{2})[.75(XFM.A) + .24LMLF(1-XM.B) - .85(LMLC.LCFLC.A)]/Y$   
+  $2LMLS(v_{Si}^{1} + v_{Si}^{2}) + .14LMLA(v_{A1}^{1} + v_{A1}^{2}) + .08LMLNv_{Ha}^{2}$   
+  $v_{Ca}^{2}[.85LMLC - .75LCMLC - .25(LMLF.LCFLC)]/Y = 0.0 ....(8a)$ 

2) For amphibole, recall eqn. (6d); in (6c)  $v_{Hg}^{5}$  etc. is replaced by  $(v_{Hg}^{4} + v_{Hg}^{5})$  etc. 2.9d $\mu_{Hg}$ /dx + 1.4d $\mu_{Fe}$ /dx + 6.2LMLS $v_{Si}^{5}$  + 2.6LMLA $v_{A1}^{5}$  + 1.8L $_{HaHa}$  d( $\mu_{Ca}$ )/dx + .9LMLN $v_{Na}^{5}$  = 0

+ 
$$v_{Ng}^{5}$$
 [2.9(1-XF.A) + 1.4LMLF.XFM.B - 1.8LMLC.LCMLC.B]/ Y +  
 $v_{F_{0}}^{5}$  [2.9(XFM.A) + 1.4LMLF(1-XM.B) - 1.8LMLC.LCFLC.A]/ Y +  
5 6.2LMLSv  $s_{1}$  + 2.6LMLAv $s_{A1}^{5}$  + .9LMLNv $s_{N_{B}}^{5}$  +  
 $v_{C_{A}}^{5}$  [1.8LMLC - 2.9LCMLC - 1.5LMLF.LCFLC]/ Y = 0.0 ....(8b)

3) For Gt, recall eqn. (6e) and substituting results from eqn (7.5)  $.86d\mu_{Hg}/dx + 1.6d\mu_{Fe}/dx + 3LMLSv_{Si}^{S} + 2LMLAv_{A1}^{S} + 0.54L_{HeMg}d(\mu_{Ca})/dx = 0$ 

→ 
$$v_{H_g}^{5}$$
 [.86(1-XF.A) + 1.6LMLF.XFM.B - .54(LMLC.LCMLC.B)]/Y +  $v_{F_g}^{5}$  [.86(XFM.A) + 1.6LMLF(1-XM.B) - .54(LMLC.LCFLC.A)]/Y + 3LMLS $v_{S1}^{5}$  + 2LMLA $v_{A1}^{5}$  + .54 $v_{C_a}^{5}$  [.5LMLC - .86LCMLC - 1.6LMLF.LCFLC]/Y = 0 .(8c)

Some results of these modifications, using "PLAG1", are given in Figure 7.3b & c. The main difference between these and Figure 7.3a is the formation of  $X_{Gt}^{Sya} = 0.80$  at values of  $L_{MgMg}/L_{AIA1}$ , between four and five (or three to four, using "PLAG2"). However the layer-contact reactions depend on the relative mobility of all components and  $X_{Gt}=0.8$  has a large solution volume satisfied by a large number of layer contact reactions.

A better representation of the limiting mobility of individual components is given by the L-ratio diagrams, developed by Joesten (1977), and presented in Figures 7.4 & 7.5. These diagrams are constructed by increasing various ratios at fixed values of other, independent ratios (as indicated above the figures). The contours represent the mole fraction of garnet in the symplectite for both modified "plagioclase" compositions. The solid curves represent the boundaries of corona stability, i.e. the observed corona assemblage becomes unstable when  $X_{Gt}^{Sym}$  falls below 0.66; no amphibole layer can be produced because all the available amphibole from mass balance is required in the symplectite. Similarly when  $X_{Gt}^{Sym}$  FIGURE 7.4a-f: L-ratio diagrams depicting how relative component mobilities influence the stability of the observed corona sequence. Constructed by varying diagonal L-coefficient ratios at fixed values of other independent ratios (as indicated above each diagram) and cross-coefficient ratios of -0.4. The contours represent the mole-fraction of garnet in the symplectite for "PLAG1" (--) and "PLAG2" (-----). The ruled area corresponds to solutions for XGt= 0.8, generated by the uncertainty in the reactant "plagioclase" composition. The dotted curve (----) corresponds to the contour for XGt = 0.8 and "PLAG2" with no cross-coefficient ratios.



------ REACTANT AI/SI = 0.55, ------ REACTANT AI/SI-0.61, ------ AI/8I-0.61, no X-COEffs

1.0 a symplectite layer is not produced. The ruled area represents the field for  $X_{Gt}^{Sym} = 0.8$  that is generated by the uncertainty in the reactant plagioclase composition.

Figure 7.4a to d represent succesive slices, at increasing values of  $L_{CaCa}/L_{A1A1}$ , through 3-D LMLA-LSLA-LCLA space. Calcium has to be at least 2-3 times more mobile than aluminium for the observed proportions of garnet in the symplectite to be stable. As Ca mobility increases relative to Al, the field of  $X_{Gt} = 0.8$  is displaced to higher values of  $L_{MgMg}/L_{AlAl}$ (LMLA). The uncertainty in reactant "plagioclase" is important at low values of L<sub>SiSi</sub>/L<sub>AIAI</sub> (LSLA) (Fig. 7.4b-d) where the field extends across of L /L . The symplectite proportions become a wide range approximately independent of LSLA when  $L_{M_{R}M_{R}}/L_{SiSi}$  < 0.65, i.e. Si more mobile than Mg and much more mobile than Al. Rearranging ratios in Figure 7.4b suggests that  $L_{MgMg}/L_{CaCa}$  (LMLC) cannot exceed six for any "plagioclase" composition. A lower limit on LMLC is provided by Figure 7.4f where the corona becomes unstable if LMLC becomes less than one, i.e. Ca becomes more mobile than Mg. In Figure 7.3 LMLC and LMLS are equal to one and increasing LMLA is equivalent to points at LMLA,LSLA=1,5,10,20 respectively in Figure 7.4a to d. Note that the proportions of garnet in the symplectite increases with increasing LMLA, at fixed values of LMLC (i.e. increasing LCLA), but decreases at fixed values of LCLA (i.e. increasing LMLC).

Cross-coefficient ratios are fixed at the arbitrary value of -0.4 in Figure 7.4. The effect of neglecting cross-coefficient terms for the most aluminous reactant ("PLAG2") is given by the dotted curve(s) of  $X_{Gt} = 0.8$ . It requires higher  $L_{CaCa}/L_{AIA1}$  (LCLA) to satisfy  $X_{Gt}^{Sym}$  and displaces the symplectite proportions to lower values of  $L_{MgMg}/L_{AIA1}$  and to  $L_{MgMg}/L_{CaCa}$ < 2-4. Contours for cross-coefficient ratios less negative than -0.4 lie at intermediate positions. As stated earlier the less aluminous "plagioclase" cannot produce enough garnet in the symplectite.

The curves from varying  $L_{NgNg}/L_{FeFe}$  (Fig. 7.4e) have a different form and the field of corona stability is relatively narrow and restricted to LMLF less than 2-4, suggesting that Mg and Fe must have similar mobility, especially if no cross-coefficient terms are introduced. In addition the corona becomes unstable if LCLA exceeds 12-14 when  $L_{NgNg}/L_{A1A1}$ =10, i.e. LMLC < 0.83-0.71. In contrast, an amphibole layer is produced for a large range of  $L_{NgNg}/L_{NANA}$  (LMLN), but  $X_{Gt}$ =0.8 is restricted to LMLN < 6-8 for

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FIGURE 7.5a & b: L-ratio diagrams showing the effect of varying crosscoefficient ratios on corona stability, while diagonal L-coefficient ratios are fixed at the values indicated above the diagrams. Key as in Figure 6.



FIGURE 7.6: The effect of whole rock chemistry on corona proportions in the steady state exchange cycle at fixed plagioclase composition and for a given set of L-coefficients.



both plagioclase compositions when LCLA is less than 12-14 (Fig. 7.4f), and is less than two if no cross-coefficient terms are introduced.

As mentioned earlier, the choice of cross-coefficent ratios has a significant influence on the proportions and stability of a symplectite (Figs. 7.3 & 7.5). If they become more negative and exceed -0.4 to -0.6, at increasing values of LMLA (Fig. 7.5a) and LMLC fixed at one (i.e. increasing LCLA), no symplectite is produced and monomineralic garnet and amphibole layers form. If cross-coefficients are not introduced (i.e.  $L_{CaHg}/L_{CaCa}$ ,  $L_{CaFe}/L_{CaCa} = 0$  with "PLAG1" as a reactant, all the amphibole occurs in the symplectite, and it is impossible to generate the necessary proportions of garnet in the symplectite. However this can be achieved for the aluminous "PLAG2" reactant, provided LMLA exceeds eight. The effect of including cross-coefficient ratios on LCLA is shown in Figure 7.5b. This Figure is more useful and implies that at low values of LCLA, high negative values of the cross-coefficient ratios are necessary to obtain  $X_{6+}$  whereas, at higher values of LCLA, there is a restricted range of cross-coefficient ratios that satisfy  $X_{6t}^{sym}$ . Thus Ca and Al could have similar mobility provided cross-coefficient terms are large enough, but LCLA must always exceed 1.5-2.0 (Fig. 7.5b).

Representative layer contact reactions for LMLF,LMLS,LMLA, LMLC,LMLN at 1,10,30,3,1 respectively and cross-coefficient ratios of -0.9, are given below; water is assumed to be perfectly mobile, thus eliminating any chemical potential gradients in  $H_2O$  and resulting in negligible flux: (1) Olivine/Orthopyroxene layer contact:

4.65 OL + 0.21SiO<sub>2</sub> + .09A10<sub>1 5</sub> + 2.42 OPX + 2.00MgO + 2.45FeO

(2) Orthopyroxene/Clinopyroxene layer contact:

0.84 OPX + .06A10 + .86Ca0 + .15Na0 + .36S10 + 1.04 CPX + 0.33Mg0 + 0.32Fe0

(3) Clinopyroxene/Amphibole layer contact:

D.31 CPX + .03Fe0 + .05Al0<sub>1.5</sub> + .09Na0<sub>.5</sub> + .05H<sub>2</sub>0 + .05 AMPH + .11Mg0 + .30Si0<sub>5</sub> + .17Ca0

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(4) Amphibole/Symplectite layer contact:

0.22 GT + .06 AMPH + .17MgO + .13SiO<sub>2</sub> + .11CaO + .19NaO<sub>.5</sub> + H<sub>2</sub>O + .19 AMPH + .14FeO + .14AlO<sub>1.5</sub>

(5) Plagioclase/Symplectite layer contact:

2.26 [Na  $(CaAl_{1.7}Si_{3.09}) + 2.89Mg0 + 2.84Fe0 + H_20$  $\rightarrow .37 AMPH + 1.44 GT + .40Si0_2 + .02Al0_{1.5} + .82Ca0 + .50Na0_5$ 

Overall exchange cycle: 4.65 OL + 2.26[Na\_4 CaA1\_1.7 Si\_3.09] + H<sub>2</sub>O + 1.58 OPX + 0.74 CPX + .55 AMPH + 1.21 GT

A similar set of L-ratio plots are obtained for the (cpx-gt) symplectite-bearing corona in sample DMS-8. The matrix of linear equations is presented in Table 7.5. Here the calculated mole fraction of garnet in the symplectite is between 0.7 and 0.75. It can be modelled in the FCMAS system as there is no amphibole and sodium can be ignored in the models. The components are listed in Table 7.3 and the exchange cycle for LMLF, LMLS,LMLA, LMLC equal to 1.10.30.3 respectively is given in Figure 7.6.

Figure 7.6:  $\frac{4.22 \text{ OL} + 0.15 \text{ AlO}_{1.5} + 0.20 \text{ SiO}_{2} \text{ f}}{2.22 \text{ OPX} + 2.0 \text{ MgO} + 2.01 \text{ FeO}}$ (1)  $\frac{0.68 \text{ OPX} + 0.15 \text{ AlO}_{1.5} + 0.60 \text{ CaO} + 0.23 \text{ SiO}_{2} \text{ f}}{0.54 \text{ CPX} + 0.15 \text{ MgO} + 0.24 \text{ FeO}}$ (2)  $\frac{0.18 \text{ CPX} + 0.20 \text{ FeO} + 0.13 \text{ SiO}_{2} + 0.18 \text{ AlO}_{1.5}}{0.05 \text{ CPX} + 0.12 \text{ GT} + 0.05 \text{ MgO} + 0.06 \text{ CaO} \text{ f}}$ (3)  $\frac{1.62 \text{ GT} + 0.55 \text{ CPX} + 0.26 \text{ SiO}_{2} + 0.68 \text{ CaO} + 0.02 \text{ AlO}_{1.5}}{2.05 [\text{Ca}_{1}(\text{Si}_{1.82}\text{ Al})_{1.7}] + 2.02 \text{ MgO} + 2.50 \text{ FeO} \text{ f}}$ (4) Overall exchange cycle:

4.22 OL + 2.05 [Ca, (Si, 21), 1 + 1.68 OPX + 1.37 CPX + 1.50 Gt

TABLE 7.5: Matrix form of the steady state diffusion model for DMS-8; an opx-cpx-{cpx-gt}sym corona.

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## 7.5 THE EFFECT OF VARIABLE MINERAL CHEMISTRY ON THE DIFFUSION MODELS

A range of samples with different coexisting sets of Mg numbers have been modelled in an attempt to determine the effect of whole rock composition on the mineral proportions and stability of layer sequences. When samples with lower Mg contents are considered for a given set of L-coefficients and fixed "plagioclase" composition,  $X_{Gt}^{aym}$  is approximately constant but there is a significant decrease in the Opx/Cpx and Opx/Gt ratios. Results for a range of olivine and coexisting corona compositions are plotted in Figure 7.7.

## 7.6 CONCLUSIONS

Corona-forming reactions in metagabbros from the Central Gneiss Belt represent a single-stage, subsolidus process and resulted in garnet-bearing symplectite layers. The later reaction history is complex and multi-stage. Early reactions were diffusion-controlled and have been modelled in terms of steady-state diffusion in an attempt to estimate relative component mobilities. Mobilities are represented by L-coefficient ratios and this study has tried to restrict the solution sets of L-coefficients that produce exchange cycles consistent with the observed mineral proportions. Many assumptions were made in the models and the results are only qualitative. One major problem is the difficulty in assigning a reactant plagioclase composition because of complementary reactions within matrix plagioclase. Two limiting ratios have been used and the following results obtained:

- (i) In the coronas, aluminium has to have restricted mobility to produce the observed mineralogy and ultimately its mobility may be rate-controlling.
- (ii) The presence of a symplectite suggests that both Al and Si have restricted mobility, with Al less mobile than Si.
- (iii) Mg.Fe must have similar mobility as the symplectite becomes unstable if  $L_{M_{B}M_{C}}/L_{F_{B}F_{C}}$  exceeds two to four.

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- (iv) Cross-coefficient terms from "uphill" Ca-diffusion are required to produce the necessary symplectite proportions and significant amounts of monomineralic amphibole when using less aluminous "plagioclase" compositions.
- (v) Sodium mobility has little effect on overall corona stability. However  $L_{MgMg}/L_{NaNa}$  is restricted to less than 6-8 to produce the necessary proportions of garnet in the symplectite.
- (vi) Determining the lower limit of calcium to aluminium mobility is problematical because of the proposed interaction with cross-coefficient terms; Ca can have low mobility at correspondingly high negative values of the cross-coefficient ratios, but L<sub>CaCa</sub>/L<sub>AIAI</sub> must be greater than 1.5-2.0.
- (vii) Magnesium must be at least as mobile as calcium and probably more so. However L /L must not exceed 4-6 at cross-coefficient ratios of -0.4, or 2-4 without cross-coefficient terms.
- (viii) Irrespective of the values for the cross-coefficient ratios, the symplectite proportions become independent of  $L_{SiSi}/L_{AIAI}$  when Si becomes more mobile than Mg. This is unlikely and as a result the value of  $L_{MgHg}/L_{AIAI}$  is strongly dependent on the reactant "plagioclase" composition.

In the next Chapter the theme of disequilibrium is continued in a study of sapphirine-bearing lithologies collected from tectonite zones within the CGB. Again restricted mobility of aluminium is an important control on the complicated reaction textures and likely P.T constraints have been placed on the various stages within the textural evolution.

### CHAPTER VIII

# TECTONIC IMPLICATIONS FROM SAPPHIRINE-BEARING LITHOLOGIES

### 8.1 INTRODUCTION

Chapters 6 and 7 presented a detailed discussion of the tectonic significance of metastable and disequilibrium assemblages in coronite metagabbros. They were also mentioned briefly in Chapter 5 with respect to garnet peridotites and this Chapter continues this theme by considering reactions in sapphirine-bearing lithologies. In each case the reaction textures persisted metastably during granulite facies metamorphism at 1.1-1.0 Ga. because of slow reaction rates, where either availability of components, or difficulty in nucleation/dissolution was rate-controlling. These assemblages are found in boudins which must have resisted penetrative deformation and micro-fracturing to survive the catalytic effects from infiltrating fluids. Furthermore, slow reaction kinetics and the probable absence of a free fluid after 1.0 Ga. were presumably also responsible for the metastable preservation of granulite and upper amphibolite facies host gneisses during uplift.

Sapphirine-bearing rocks are found in magnesian metabasic lenses from three localities within the Central Gneiss Belt (CGB) in SW Grenville Province: (1) in Rosseau subdomain where it occurs in a crudely layered mafic pod (S in Figs. 2.2 & 3.5), enclosed in a sliver of anorthositic gneiss from an internal tectonite zone; (2) in mafic meta-eclogitic pods from an internal shear zone in Britt domain near the village of Arnstein, a few kilometers north of the northern end of Parry Sound domain (S in Fig. 2.2); (3) from two adjacent boulders in glacial moraine that probably have not travelled far from their source which would then also be in Britt domain. The field relations and an introductory report on the mineralogy Of the Rosseau and Arnstein localities is presented in Davidson et al. (1982).This Chapter elaborates further on their work and attempts to constrain a P-T path for the complicated reaction history. It is important to note that as with boudins of garnet peridotite (Chapter 5), the sapphirine-bearing samples have so far only been identified in association with tectonite zones in which unknown amounts of differential movement

have taken place, prior to re-equilibration under granulite and upper amphibolite facies conditions. Sapphirine is reported elsewhere in the Grenville Province but mainly in metasediments, such as the sapphirinebearing lens in metasedimentary granulite belonging to the Grenville Super-Group in Quebec, reported by Herd et al. (1986) and in a paragneiss from Central Labrador (Kerrich & Thomas, 1986).

Sapphirine is a highly aluminous and magnesian mineral which, once formed. tends to preserve a wealth of reaction textures within microdomains of a thin section where stable contacts are typically restricted to minerals of similar Al/Si ratios. The likely explanation is that the formation of sapphirine locks up Al and hence Mg which is then difficult to remobilise. The localised sites of sapphirine formation may been attributed to variations in the Al-content of the protolith; in metasediments it has been described in Mg and Al-rich pelitic layers or palaeosols, where extraction of an Fe-rich partial melt may have enhanced the magnesian and peraluminous nature of the protolith (Lal et al., 1978; Droop & Bucher Nurminen, 1984). Furthermore, subtle differences in bulk composition on a smaller scale, either primary or by extraction or removal of material (especially SiO,), can have a significant effect on the various sapphirine-bearing assemblages that form (Tracy & McLellan, 1985; Herd et al., 1986; Ackermand et al., 1987). In the examples discussed here. sapphirine is present in metabasic lenses where Ca is an important contributor to the whole rock chemistry. It is similar to other accounts of sapphirine in meta-igneous rocks, including Sills et al. (1983) and Johansson & Moller (1986), where sapphirine is described in layered magmatic complexes. The sapphirine-bearing rocks have not been analysed, but the relatively high Na and Ca contents (reflected in plagioclase) suggest that an original ultramafic composition, such as the garnet peridotites, is unlikely and a gabbroic protolith, more magnesian than the coronite metagabbros, is preferred.

## 8.2 PETROGRAPHY

This section is subdivided into the two meta-igneous sapphirine associations identified in the CGB: I - the layered mafic lens within highly tectonised anorthosite; II - the eclogitic pods with foliated amphibolite rims.

## I - LAYERED MAFIC LENS (85DMSR-3, 81DMN-389A and 85DMSR-13A)

This consists of crudely alternating mafic and plagioclase-rich layers in a mafic pod within anorthositic gneiss and may represent a gabbroic cumulate genetically related to the anorthosite. In hand specimen the mafic layers comprising opx-cpx-amph-plag, are separated from pale blue sapphirine-plagioclase domains disseminated garnets. by The mineralogy of these two layers (domains) is summarised in Table 8.1. Sapphirine is only present in the plagioclase domains and occurs as finegrained "knots" intergrown with plagioclase in a granoblastic matrix of plagioclase, garnet, amphibole and minor biotite (Plate 8.1a & b). Plagioclase exhibits strong reverse zoning (Plate 8.1b) and also encloses independent clusters of spinel and less common corundum rods. These occur adjacent to but not intergrown with sapphirine clusters (Plate 8.1a), suggesting very local controls on the reactions taking place. Garnet forms sub to euhedral crystals around the margins of the plagioclase domains, but has been corroded by sapphirine in the interior where the gross morphology of the sapphirine knots suggests many are direct pseudomorphs after garnet (Plate 8.1c). The mafic layers consist of opx-cpx-amph-plaggt where amphibole variably replacing pyroxene, has incompletely converted the layers to garnet amphibolite.

The sample contains two generations of amphibole: pale green to yellow amphibole as part of the equilibrium assemblage in plagioclase domains, whereas green to bluish green amphibole is retrogressive on pyroxene in the mafic layers. The textural relations of garnet are more complex: in the plagioclase domains it has been replaced by sapphirine but was relatively stable at the margins and within mafic layers, where it occurs as anhedral grains intergrown with amphibole. At the edge of one mafic layer, garnet with an aluminosilicate inclusion has a rim which extends and envelops relict spinel (Plate 8.1d). This apparently postdates sapphirine-forming reactions and is further substantiated by similar, advanced reactions in sample 85DMSR-13A. This comes from a mafic pod associated with the same anorthosite sliver a few kilometers further west and contains knots of corundum-spinel-mica enveloped by a necklace of garnet and retrogressive amphibole (Plate 8.2a), being superficially similar, but more hydrated than the association in Plate 8.1d.

Sample 85DM-203 exhibits similar textures to the plagioclase domains in 85DMSR-3. It comes from one of the erratics but it too may represent

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## PLATE 8.1

- A: Independant clusters of sapphirine and spinel-corundum "knots" in 85DMSR-3 (association I) from Rosseau subdomain.
- B: Crossed polars view of Plate 8.1A showing the strong reverse zoning of plagioclase adjacent to garnet and sapphirine.
  - C: Sapphirine-anorthite intergrowths from association I, in the form of pseudomorphs after sub- to euhedral garnet (850M-230).
  - D: Garnet necklace enveloping relict spinel at the edge of the mafic layer in 85DMSR-3 (association I). Garnet also contains an aluminosilicate inclusion.

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SAMPLE	QTZ	PLAG	BIOT	AMP	GT	OP	CPX	OPX	KY	SAPP	COR	SP	RUT	MUSC	ÉPIC	) Commenta
850MSR-3		×		*x	*	 X	 ¥	 х	×		*					Hf laver
810MA-389A		X	X		x		~		X?	x	X	x				Plag layer
85DMSR-13A	****	X	x	X	X	X					X	X		X		Retro sapp
810MN-155E	×	X	χ	X	х х	 X	X		×		 X	×	x	X		Musc-cor-spin
810MN-155F	~x	x		X	X	X	X	X	X	x	X		x			-
810MN-155G	x	x		X	X			X	x	x	x	x		x		
850M-202	 ^	 X	 X	 X	×	 X			 X		 X	 X	 X		 X	
850M-203		x	x	X	X				x	X	X		x	x		
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TABLE 8.1: Assemblages found in sapphirine-bearing rocks (\* refers to two generations; " refers to qtz incl in garnet).

TABLE 8.2: Summarised mineral compositions and zoning characteristics (\* sapphirine association; + spinel only; rev - reverse zoning; Rx - recrystallised; Mf - mafic layer).

SAMPLE	PLAG	GARNET			CPX		OPX	SAPP	SPIN	*AMPH	PHLOG
			Mg No.	Mg N	o. CaT	s Jd	Mg No.				
95DMSR-3	*An80-93	*And2Py47Sp1Gr14A1m36(C	) 55(A)								
B10MA-389A		*And2Py48Sp1Gr9A1m40(R)	54	80	2	3	75-77	84	56	75	83
		[Fe(Ca)-1]									
		+And8Py37Sp1Gr8A1m46(R)	42(C)								
	An42-52(rev)	And1Py32Sp1Gr24A1m42(Mf	) 42(B)								
10MN-155E	+An67	+And4Py39Sp1Gr17A1m39(C	) 49	79	4	6-7	-		50	66	-
		+And3Py39Sp1Gr13A1m43{R	) 46								
		[Fe(Ca)-1]									
	An31-37(rev)	And3Py35Sp1Gr17A1m44	43								
810MN-155F	*An93	*And3Py58Sp1Gr13A1m25(C	) 68	88	11-14	7-12	82	90	-	84	-
	An38-38	*And4Py54Sp1Gr11A1m3D(R	) 63	90 ( R:	c) 7	6					
		[Fe(CaFe)-1]									
310MN-155G	*An80	*And3Py49Sp2Gr16Alm31(C	) 59				77	86	55	81	-
	An39-50(rev)	*And2Py45Sp1Gr16A1m36(R	) 55								
		[Fe(Mg)-1], slight *[Fe(	Ca)-1]								
350M-202	*An88	*And2Py44Sp1Gr19Alm34(C	) 55	81	5-13	5-9		84	61	78	82
	An33-40(rev)	*And1Py40Sp1Gr17A1m40(A	) 50								
		[Fe(ca,Hg)-1]									
ISOM-203	*An80-84	*And6Py49Sp1Gr8A1m37(C)	54	-			-	85	-	76	79
	An42-53(rev)	*And5Py51Sp1Gr4Alm39(R)	54								
		[(Fe,Mg)Ca-1]									
SOMSR-13A	An40-52(rev)	And2Py34Sp2Gr18A1m45(C	) 42	-			-	-	47	71	78
		+And3Py35Sp1Gr13A1m49(R	) 40								
		[Fe(Ca)-1]									

### II - ECLOGITIC PODS (81DMN-155E, F, G AND 85DM-202)

In this case the original mineralogy consisted of gt-cpx-ky<u>+</u>plag where kyanite occurs along with rutile and quartz as inclusions in garnet porphyroblasts. Plagioclase is present both as intergrowths or inclusions within clinopyroxene and as rims separating clinopyroxene from garnet. The rocks are referred to as eclogitic because most if not all the plagioclase may have formed by decompression reactions involving garnet and Cpx. This resulted in the cpx-plag symplectites (Plate 8.2b) where the Cpx host has remained in optical continuity, a common observation in eclogitic rocks (e.g Griffin & Raheim, 1973; Boland & Van Roermund, 1983); the latter ascribing the mechanism of exsolution to a discontinuous precipitation reaction. Rare orthopyroxene lamellae are present in clinopyroxene cores, whereas it has recrystallised into a granoblastic pyroxene-plagioclase mosaic at the margins which is variably replaced by pale green amphibole. In addition, one sample (85DM-202) contains clinozoisite and this too probably represents part of the original high pressure assemblage because it is surrounded by later reaction rims involving corundum and spinel.

Sapphirine is present as a reaction product and occurs in several associations: (1) as rims intergrown with plagioclase + white mica around kyanite partially enclosed within garnet (Plate 8.2c); (2) as rims on kyanite separated from orthopyroxene and quartz by white mica and plagioclase (Plate 8.2d); (3) as knots in matrix plagioclase occasionally intergrown with rutile, corundum and spinel (Plate 8.3a). Morphologically knots consist of fine-grained vermicular sapphirine which has prethese dominantly replaced garnet because the latter has large, concave embayments adjacent to sapphirine (Plate 8.3c). The transformation of kyanite and garnet (1) is not isochemical because kyanite, completely enclosed within garnet, typically does not show any evidence of incipient reaction and suggests that some other mafic minerals including clinopyroxene, must Clinopyroxene was involved in the formation of corundumbe involved. spinel around clinozoisite (Plate 8.3d). Sample 81DMN-155E is the most to olive green amphibole exhibits extensive green evolved and retrogression on clinopyroxene and the replacement of sapphirine knots by mica-corundum-spinel+opaques.

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## PLATE 8.2

- A: More evolved sample from the anorthositic association in Rosseau subdomain (85DMSR-13A). There is no sapphirine but relict corundumspinel knots are enveloped by a discontinuous garnet necklace.
- B: Vermicular clinopyroxene-plagioclase symplectite from a metaeclogite in association II (85DM-202).
- C: Meta-eclogite (81DMN-155F) where a garnet-kyanite has reacted to produce sapphirine-plagiolcase<u>+</u>mica.
- D: Higher magnification of the association in Plate 8.2C showing the sapphirine mantle on kyanite.



0.125mm
# PLATE 8.3

- A: Kyanite mantled by sapphirine and separated from orthopyroxenequartz by plagioclase; association II, sample 81DMN-155G.
- B: Knots of rutile-sapphirine adjacent to garnet that contains inclusions of quartz and rutile. Sapphirine is also directly replacing garnet in the bottom of the picture. Association II, sample 81DMN-155F.
- C: Meta-eclogitic association (81DMN-155G) where garnet has been partially replaced by fine grained sapphirine intergrowths and relict clinopyroxene has exsolved plagiolcase while retrogressive amphibole has developed at it's margins.
- D: Zoisite in 85DM-202 surrounded by corundum and separated from clinopyroxene by plagioclase; association II.

A B Sa Rut Qtz 0.5mm D C Zois

0 · 125mm

# 8.3 MINERAL CHEMISTRY

The mineral chemistry is summarised in Table 8.2 and in Figures 8.1-8.4. All the minerals associated with sapphirine are magnesian and the Mg number varies consistently according to Sapp > Biot > Cpx > Amph > Opx > Spin > Gt. The analyses, with the exception of 85DMSR-13A, were carried out by WD techniques at the University of Kiel (FDR); means and corresponding standard deviations are presented in Appendix III.

#### Pyroxene

Clinopyroxene in association I is a diopsidic augite with low contents of jadeite and Ca-tschermaks molecules (Fig. 8.1a). In the metaeclogites (association II) clinopyroxene cores commonly retain high Na,Al contents and although not strictly omphacites (Clark & Papike, 1968), they become more so if the exsolved plagioclase is reintegrated into the pyroxene. The recalculated site occupancies are plotted in Figure 8.1b & c and there is a good positive correlation between octahedral Al and Na or Al(IV), corresponding to progressive loss of Al as both Jd and Ca-Ts molecules during recrystallisation and exsolution of plagioclase.

## Plagioclase

Matrix plagioclase ranges from  $An_{32-50}$  and shows reverse zoning whereas plagioclase exsolved from cpx is more restricted in composition at  $An_{31-37}$ . Plagioclase adjacent to or intergrown with sapphirine is considerably more calcic  $(An_{74-93})$  and exhibits strong reverse zoning by up to 20 molf An.

#### Garnet

The compositional variation in garnet is complicated (Fig. 8.2) and in 85DMSR-3 (association I) there appears to be at least three garnet generations (Table 8.2): adjacent to sapphirine garnet rims are depleted in grossular by  $Fe[Ca_{M}g]_{-1}$  exchange (Gt A), although there is negligible zoning if both core and rim are Ca-depleted which suggests grossular is lost during reaction. Furthermore this garnet is always considerably more magnesian than garnet in the mafic layer (Gt B) by  $Mg[CaFe]_{-1}$  exchange. Thus garnet in local equilibrium with sapphirine is consistently low in calcium and during retrogression and later reaction, as documented by 85DMSR-13A, the garnet again becomes more Fe and Ca-rich (Table 8.2), similar to garnet surrounding spinel in 85DMSR-3 (Gt C, Plate 8.1d) which comes from near the edge of the mafic layer. In association II the

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FIGURE 8.1: Recalculated pyroxene end-members (a) and site occupancies (b & c) for WD analyses from sapphirine-bearing rocks.



FIGURE 8.2: a - recalculated garnet end-member compositions (c,r in DMSR3-A refer to core and rim compositions for Gt A in Table 8.2); b - Sapphirine compositions recalculated to include Fe3 and plotted in part of the SiO2-(Mg,Fe)O-(A1,Fe)2O3 triangle.





grossular content is variable but rims are similarly depleted in calcium adjacent to sapphirine. In 81DMN-155E sapphirine has apparently been replaced by spinel-corundum and the garnet is similar to the Gt-C composition in DMSR-3 and DMSR-13A that envelops spinel.

## Aluminosilicates

These are present as inclusions within garnet in every sample, except 85DMSR-13A. In most cases the good cleavage and low birefringence indicate the kyanite polymorph although this is less certain in 85DMSR-3. The inclusions are commonly pale blue and the colour correlates approximately with increased contents of  $Cr_2O_3$  (up to 6 Wt% in DMN-155E, but normally from 0.1-0.5 Wt%) although the Cr-content is less than 0.01 Wt% in DMSR-3. Iron is present as Fe<sup>3+</sup> in minor amounts (up to 1 Wt%).

## Sapphirine

This consistently occurs in relatively fine-grained intergrowths which exhibit no detectable chemical zoning. The analyses have been recalculated to include  $Fe^{3+}$  following Higgins et al. (1979) and the resulting  $Fe^{3+}/(Fe^{3+}+Fe^{2+})$  ratios ranges from 0.13 to 0.36 with a mean of 0.24. The recalculated compositions are plotted in part of the SiO<sub>2</sub>-(FeO+MgO)-(Al<sub>2</sub>O<sub>3</sub>+Fe<sub>2</sub>O<sub>3</sub>+Cr<sub>2</sub>O<sub>3</sub>) system in Figure 8.2b and lie on or near the line that represents coupled MgSi=AlAl substitution, close to the [7:9:3] composition with most being referred to as peraluminous (especially 81DMN-155G). Minor amounts of chrome are present in sapphirine from association II but this is always negligible in DMSR-3 (association I).

## Spinel

The Mg number of spinel ranges from 47-66 (Table 8.2) and it is always considerably more Fe-rich than coexisting sapphirine. Furthermore it is not present in 81DMN-155F and 85DM-203 which also contain the most pyrope-rich garnets. In addition to hercynite-spinel, the analyses include zinc as a major constituent (up to 1.5 Wt%) and minor Cr and Ni (up to 0.6 Wt%).

#### Amphibole

The pale green amphibole associated with sapphirine ranges from a pargasite or pargasistic to magnesio-hornblende (Leake, 1978). The recalculated site occupancies are plotted in Figure 8.3. where the compositional variation is represented by the pargasite and tschermaks



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IGURE

00

<u>ب</u>

site

occupancies

from sapphirine-bearing

vectors (Fig. 8.3b & c), together with a coupled substitution for Ca (Fig. 8.3d).

OTHER CONSTITUENTS: biotite, white mica, rutile, corundum & clinozoisite.

Biotite is phlogopitic with Mg numbers of 79-83. The Ti-content is generally low, although this varies from 1-2 Wt% in 85DMSR-3 to 4 Wt% in 85DM-202. White mica is commonly present adjacent to sapphirine or spinel<u>+</u> corundum and is highly aluminous (34-37 Wt%  $Al_2O_3$ ). Rutile is an accessory in 81DMN-155F,G and 85DM-202 and is almost pure TiO<sub>2</sub> with minor Fe and Cr. Corundum contains accessory Fe (up to 0.5 Wt%) and Cr (0.1 Wt%). Clinozoisite is present in 85DM-202 and contains Fe,Mg and Ce as essential constituents and is strictly allanite.

# 8.4 PHASE RELATIONS

The strong reverse zoning in plagioclase together with the finegrained and localised nature of the aluminous products suggest that limited diffusion of Al was rate-controlling during the reactions. Thus it should be possible to model reactions as isochemical with regard to Al and, in this respect, the mechanism may be analogous to the formation of spinel-clouding in plagioclase from coronite metagabbros (Chapters 6 & 7); here' sapphirine might have been produced if the metagabbros had been more magnesian. The phase relations of the various sapphirine-bearing lithologies are plotted in Figure 8.4; Figure 8.4b is a projection from quartz onto the Al $_{2}$  O<sub>3</sub>-CaO-(Mg,Fe)O plane by condensing on the FeMg\_1 and NaSi(AlCa)\_\_\_ exchange vectors and is similar to an ACF diagram. Although quartz is not present in all samples (in some cases only observed as inclusions within garnet), silica does participate in the reactions and in each sample the projection refers to phase relations at fixed silica activity (< 1). It was constructed in an attempt to illustrate the breakdown of the gt-cpx-alsil tie-lines. The two different sapphirine associations are discussed separately below and the following simplified mineral compositions have been adopted in writing reactions:

CHAS system  $Gt - Ca_{.5} Mg_{2.5} Al_2 Si_3 O_{12}$ ;  $[7:9:3]Sapp - Mg_{3.5} Al_9 Si_{1.5} O_{20}$ ; Hbl -  $Ca_2 Mg_4 Al_2 Si_7 O_{22} (OH)_2$ . FCMAS system  $Gt - Ca_{.5} Mg_{1.5} Fe_1 Al_2 Si_3 O_{12}$ ;  $Cpx - Mg_{.8} Fe_{.2} CaSiO_6$ ;  $Opx - Mg_{.8} Fe_{.2} SiO_3$ ; Hbl -  $Ca_2 Hg_3 Fe_1 Al_2 Si_7 O_{22} (OH)_2$ ;  $[7:9:3]Sapp - Mg_3 Fe_{.5} Al_9 Si_{1.5} O_{20}$ . FIGURE 8.4: a - mineral compositions plotted in SiO2-{Hg,Fe}O-(A1,Fe)203 (molar proportions) triangle; b - projection from silica onto the Al203-Ca0-(Mg,Fe)O plane by condensing on exchange vectors FeMg-1 and NaSi(CaAl)-1. The primary assemblage is represented by dashed tie lines.







# I - ANORTHOSITIC ASSOCIATION (85DMSR-3, 81DMN-389A & 85DMSR-13A)

Unlike the coronite metagabbros where mineral compositions are relatively uniform within a given thin section, samples such as 85DMSR-3 testify to very restricted scales of equilibration. This resulted in a systematic variation in the Al/Si, Mg/Fe and Ca contents of individual minerals particularly garnet, clinopyroxene and plagioclase within specific domains of a thin section. At best the samples can be considered in terms of heterogeneous equilibration (Tracy & McLellan, 1985) where mineral compositions are relatively constant at mutual contacts within similar assemblages or sub-domains, but where a given phase may vary in composition between various sub-assemblages. In each case volume diffusion within garnet was not rapid enough to allow complete re-equilibration of sapphirine with low grossular compositions and commonly only garnet rims are depleted. Small variations in bulk composition controlled the initial sites Of sapphirine development, its formation then enhanced the provinciality and led to the compositional heterogeneity of coeval and later reaction products within different subdomains of the rock.

Balanced chemical reactions cannot be written in the plagioclase domain because the replacement of garnet by sapphirine requires a rearrangement of components and a net increase in the amount of Mg. This, Coupled with the apparent stability and growth of discontinuous garnet rims between plagioclase-rich and mafic layers, suggests a complicated exchange between domains. Furthermore, as the plagioclase domains only Contain phases with high Mg numbers, it is likely that the outer garnet rim acted as an effective buffer on the Mg/Fe ratio of components diffusing into the plagioclase layers. Because sapphirine, spinel<u>+</u>corundum and less commonly corundum on its own form independent clusters, it is likely that they were unstable together (although sapphirine is sometimes associated with spinel but never with corundum). Spinel formation may depend on the availability of Si and/or Fe, spinel forming metastably with respect to sapphirine because of insufficient Mg or Si in the local environment.

It is possible to write several simplified reactions where the net result is the evolution of Si and addition of Mg to plagioclase domains. Originally olivine may have been present in the mafic layer and its transformation to orthopyroxene would be a major consumer of Si, i.e. Fo + Qtz  $\rightarrow$  2En. Garnet and hornblende may then form by 6En + 2An + 0.5Diop → Hbl + Gt + Qtz.

Combining these and conserving enstatite:  $3Fo + 0.5Diop + 2An + 2Qtz \rightarrow Gt + Hb1.$ 

These represent simplified reactions in the CMAS system and mask the overall  $MgFe_{-1}$  exchange from mafic to plagioclase domains. In the latter the formation of sapphirine from garnet evolves  $FeO_{\pm}MgO$  and  $SiO_{2}$  and may incorporate aluminosilicates:

9Gt → [7:9:3] Sapp + 4.5An + 10.5MgO + 8.5FeO + 16.5Qtz or 2Gt + 3.5Alsil → [7:9:3] Sapp + An + 1.5FeO + 6Qtz

Possible overall reactions in the FCMAS system include: 6.5Gt + 15.2An + 16Cpx + 400px → 17Hbl + [7:9:3]Sapp Gt + 160px + 7An → 7:9:3Sapp + 4Hbl + 5Qtz

Later retrogressive reactions such as Sapp  $\rightarrow$  Mica + Cor + Spin (85DMSR-13A) were probably promoted by fluid influx during deformation which enhanced reaction kinetics. As in the preceding reactions Al can remain effectively in place while the bulk assemblage equilibrates to more Fe- and Ca-rich compositions.

# II - ECLOGITIC SAMPLES

The reactions in this association are a little easier to deal with although they may involve some bulk exchange of Fe,Mg etc. Initial reactions are represented by the exsolution of plagioclase from omphacitic clinopyroxene, i.e. Jd + Qtz  $\rightarrow$  Ab and Ca-Ts + Qtz  $\rightarrow$  An.

During decompression Ca-tschermak can also react with garnet to produce diopside and sapphirine:

1.8Ca-Ts + 2.7Gt + 3.2Diop + 2[7:9:3]Sapp + 3.5An + 6.50tz

Several other possible reactions are represented in the projections in Figure 8.4. The breakdown of garnet and kyanite to sapphirine can be represented by 2Gt + 5.4Ky + 7.3Gtz + 1.4[7:9:3]Sapp + An

- quartz in these reactions being consumed during the exsolution of plagioclase from high-Al cpx. It is possible that kyanite was retained

preferentially within garnet; the reaction between kyanite and grossular to produce anorthite or sapphirine requiring Si and Mg respectively and being limited by relatively slow volume diffusion of Si and/or Mg in garnet. As in 81DMN-155G and the sapphirine-bearing mafic rocks described by Johannson & Moller (1986), kyanite was probably originally present throughout the pyroxene-rich matrix and disappeared by reactions such as:

> Diop + Ky + H<sub>2</sub>O  $\rightarrow$  En + An + Hbl and Diop + Ky  $\rightarrow$  [7:9:3]Sapp + 3.5An +6.5Qtz

In 81DMN-155G there is a further reaction between kyanite and orthopyroxene: 4.5Ky + 3.5En  $\rightarrow$  [7:9:3]Sapp + 6.5Qtz {Fig. 8.4}

- where quartz is separated from sapphirine-plagioclase by opx (Plate 8.3a). Clinozoisite is an additional reactant in 85DM-202:

2Clinozoisite  $\rightarrow$  Cor + 2An + 2Qtz coupled with, CaTs + Qtz  $\rightarrow$  An.

The role of amphibole in the sapphirine-forming reactions is equivocal. It could be important as in:

6Ky + Hb1 → 1.1[7:9:3]Sapp + 2An + 7.4Qtz.

Alternatively it may be simply replacing pyroxene: 1.5Diop + Gt + Qtz  $\rightarrow$  Hbl, 3En + Diop + An  $\rightarrow$  Hbl, and 3An + 90px  $\rightarrow$  Hbl + 2Gt + 2Qtz

# 8.5 P-T PATH OF METAMORPHISM

Experimental studies in the MASH system have revealed that sapphirine is stable over a wide range of P.T conditions (Schreyer & Seifert, 1968: Chatterjee & Schreyer, 1972; Seifert, 1974: Ackermand et al., 1975; Bishop & Newton, 1975). In the natural example this system is inadequate because of additional components, including FeO and CaO which increase the number of possible reactions, and the likelihood of reduced water activity. There have been many studies on the effects of FeO on phase relations in Ca-poor metasediments, e.g. Lal et al. (1984); Mohan et al. (1986); Ackermand et al. (1987). In the examples described here the presence of CaO as a major component is a further complication and, because of inadequate thermodynamic data and time restrictions, no attempt has been made to extend the reactions from the simple MASH and FMASH systems, although some relevant

end-member reactions from the MASH system have been plotted as upper stability limits in the petrogenetic grid in Figure 8.5. Sapphirine is close to the 7:9:3 composition and Higgins et al. (1979) inferred on crystal-chemical grounds that this structure should be stable at higher temperatures and lower pressures than the 2:2:1 composition. However the content of sapphirine also depends on the coexisting assemblage and Si this must be taken into account when using sapphirine composition as a P-T indicator (Bishop & Newton, 1975). The sapphirine reported here is notably less siliceous than sapphirine in metabasic layers from the lvrea zone (m9 Kbars, Sills et al., 1983), but is similar to sapphirine from the Western Gneiss Region (~9-10 Kbars, Johannson & Moller, 1986), where the estimated pressures do not correspond to bulk compositional inferences. Thus, although sapphirine in the complex natural system is not useful on its own for quantitatively evaluating the physical conditions of metamorphism, it does preserve a wealth of reaction textures which include several assemblages that are applicable to geothermobarometry and results from this are presented in Table 8.3 and Figure 8.5.

**TABLE 8.3:** P.T estimates from assemblages within sapphirine-bearing rocks (\* - indicates rim composition).

SAMPLE	GT-CPXIE & GJ	GT-OPX(HAR), (S & B)	GT-HBL(G	& PJ, [WELLS]	GT-OPX-PL-	QTZ(P & CI G	T-ALSIL-PL-QTZ(N & H]
850H\$R-3 850H\$R-13A	730-770(+80-100)	780-850 910-1000	850-870 690-730	750-770 680-720	10.4-11.2 1	0.4-12.2(max	) 11.3-13.6(min;An44 -
810MN-155E 810MN-155F 810MN155G	750-800(+40-120) 810-850(+40-90) -	- - *775-875 990-1070	*800 *670-720 *670-720	760 700-730 660-710	- - 12-12.7Kb	as (Mg)	13.5-15Kb(An37) 14-15Kb(An45) 14.5-15.5(An41)
850H-202	850-890(+70-100)	## = # ## # # # # # # # # # # # # # # #	*680-730	670-720		ħ. <b></b>	16~17Kb(An37)
850H-203		-	*655-710	740-810	-		13.3-15.2(An44)

The various geothermometers and barometers were discussed briefly in Chapter 5, section 5.4 and the problems particularly relevant here include:

a) Garnet with aluminosilicate inclusions is amenable to the garnetaluminsilicate-quartz-plagioclase (GASP; Newton & Haselton, 1981) barometer, but the very low Ca content in garnets make its application problematic because of the poorly known mixing properties at large dilutions of the grossular end-member. In addition it is uncertain how much, if any plagioclase was present in the initial equilibrium assemblage. If it is assumed that plagioclase formed and equilibrated very early during initial decompression reactions, consistent high pressures are obtained from GASP and these are compatible with an early high

- pressure eclogitic mineralogy of cpx-gt-ky+plag. In 85DM-202 and 85DMSR-3 there is no independent thermometer for the initial mineralogy and results from GASP are shown by lines A and B respectively in Figure 8.3.
- b) The plagioclase composition is variable and very little if any may have been present at the time of high pressure metamorphism. However the core matrix compositions do give consistent results in both the Gt-plagalsil-qtz and opx-gt-plag-qtz barometers. Furthermore, the pressures are only decreased by approximately 1 Kbar if the minimum An-content of disequilibrium plagioclase (An<sub>75</sub>) adjacent to sapphirine is used.
- c) High amounts of non-quadrilateral components in relict clinopyroxene from association II.
- d) The low initial Fe0 content in clinopyroxene means that relatively small variations in ferric iron determinations by charge balance methods, produce a wide range of  $Fe^{3+}/(Fe^{2+}+Fe^{3+})$  ratios and hence highly variable temperature estimates from gt-cpx thermometry; the temperature range being higher and also more restricted when all iron is taken as  $Fe^{2+}$  (the end of dotted extensions in Figure 8.5).
- e) The barometers refer to reactions with free quartz. This is not always present in the sapphirine-bearing samples and implies that the reactions, which undoubtedly involved the net transfer of silica, took place under reduced silica activity. Thus pressures estimated from the gt-opx-pl-qtz barometer (Perkins & Chipera, 1985) represent an upper maximum, while pressures from gt-alsil-pl-qtz (Newton & Haselton, 1981) a minimum, the K<sub>D</sub> for each reaction being increased and decreased respectively.
- f) The orthopyroxene-garnet thermometer (Harley, 1984a; Sen & Bhattacharya 1984) has been applied to two samples but produces high and scattered results. In contrast to the granulites where the opposite effect is observed (Chapter 5, section 5.4.2), the Harley formulation in 85DMSR-3 overestimates temperatures relative to the Ellis & Green (1979) gt-cpx thermometer by approximately 60° and this has been used as a correction factor on the gt-opx temperatures in Figure 8.5.

FIGURE 8.5: Petrogenetic grid with P,T estimates from sapphirine-bearing lithologies superimposed. Boxes refer to P,T estimates in assemblages from the host gneisses (# this study; N Anovitz pers. comm.). For discussion refer text.



The P.T estimates from 85DMSR-3 (Association I) represent the equilibration of gt-cpx-opx-plag in the mafic layers at around 11 Kbars and  $750^{\circ}C$  (Fig. 8.5), and this is assumed to be coeval with sapphirine-forming reactions in the plagioclase domains. In the eclogitic samples the initial high pressure assemblage records pressures of 14-16 Kbars and  $775-875^{\circ}C$ . Furthermore, if rim compositions are assumed to have been in equilibrium during the decompression history, the gt-opx-plag-qtz and corrected gt-opx thermobarometers give estimates of around 12-13 Kbars and  $770^{\circ}C$  respectively. Similarly, the recystallised cpx with garnet rims in 85DM-202 infers temperatures of  $\sim 775^{\circ}C$  and is shown by line C in Figure 8.5 because there is no independent pressure constraint. The temperatures estimated from garnet rims and retrogressive hornblende (using Graham & Powell, 1984) imply temperatures of around 690-720°C, in accordance with temperature sare higher in 85DMSR-3.

Later retrogressive reactions resulted in the instability of sapphirine which broke down to mica-corundum-spinel. This reaction corresponds to the reaction Sapp  $\rightarrow$  Chl + Cor + Spin in the MASH system (Seifert, 1974). It is shown in Figure 8.5 and is presumably displaced to lower temperatures in the complex natural system, with the £7:9:3Å sapphirine composition described here.

## 8.6 CONCLUSIONS

Sapphirine is peraluminous and has been preserved due to slow reaction kinetics in boudins of layered metabasites and meta-eclogites from tectonite zones in the Central Gneiss Belt. The initial high pressure mineralogy in rocks of eclogitic affinity (association II) probably equilibrated at around  $14-16\pm1-2$  Kbars and  $775-875\pm50$ °C. Later decompression reactions resulted in the instability of garnet and the exsolution of plagioclase from cpx, together with the formation of orthopyroxene, sapphirine, spinel, corundum and amphibole. In 85DMSR-3 (association I) the formation of sapphirine is coeval with equilibration of gt-cpx-opx in the mafic layer, the latter indicative of metamorphism at  $\sim 750^{\circ}$ C and 11 Kbars. This is consistent with results from later assemblages in eclogitic rocks whose equilibration was proposed to be coeval with sapphirine formation (curves A,B & C in Figure 8.5), although the

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gt-opx-plag-qtz assemblage in 81DMN-155G ( $\Delta$ , Fig. 8.5) gives slightly higher pressures. Combining these suggests that sapphirine formed at approximately 11-12 Kbars and  $750^{\circ}C$ ; 1-2 Kbars above the pressures estimated from assemblages in the host gneisses ( in Fig. 8.5)

The apparent restriction of sapphirine-bearing rocks to tectonite zones. together with an upper pressure limit of 10-11 Kbars in the lithotectonic domains after 1200 Ma. (from reactions in coronite metagabbros), supports a tectonic emplacement for the eclogitic rocks. Alternatively the high-P mineralogy could have equilibrated prior to 1200 Ma. and it was not until subsequent decompression during thrusting in the Grenvillian orogeny, that sapphirine formation took place. However this does not explain the lack of meta-eclogitic or sapphirine-bearing material within subdomains where coronite metagabbros have been well-preserved and further suggests their present location was tectonically controlled and thus the metamorphism not in-situ. It is likely that relatively rapid transport of the small eclogitic pods in shear zones allowed their fortuitous preservation (amphibolitisation being restricted to their margins) from depths of around 55 Km. Furthermore if the sapphirine-bearing assemblages in Association II do represent metastable decompression products induced by upward transport of the eclogites, it is likely that P,T estimates from these are reasonable approximates of the peak, as opposed to reset granulite facies conditions during the culmination of the Grenvillian orogeny.

## CHAPTER IX

## SYNOPSIS

The Central Gneiss Belt (CGB) in western Grenville province has been subdivided into several amphibolite and granulite facies domains, bounded by ductile shear zones and interpreted in terms of thrust tectonics. The displacements took place in the mid- to lower crust at 1.16-1.0 Ga. and numerous kinematic indicators consistently imply northwest-directed transport. Thrusting may reflect post-collisional convergence following continent-continent collision and as such, the CGB may represent the lower crustal analogue of modern orogenic belts where exposure is typically restricted to the middle and upper crust. The shear zones contain boudins Of sapphirine-bearing meta-eclogite which exhibit relict high pressure assemblages that imply these zones were actively incorporating material from depths of at least 50-55 km in thickened Grenvillian crust. Sapphirine formed during decompression and the associated assemblages record pressures of 11-12 Kbars which may represent an upper limit on the peak as opposed to reset metamorphic conditions during the Grenvillian orogeny; proposed P-T paths are shown in Figure 9.1.

Granulite facies assemblages record pressures of 8-10 kbars and temperatures of 700-750°C and equilibrated in different areas over a period of 100 Ma; ca. 1.16 Ga in Parry Sound and ca. 1.03 Ga. in Algonquin domain. Apart from the coronite metagabbros which represent relatively minor additions to the crust, there is no known syntectonic plutonism associated with the Grenvillian cycle in the CGB (ca. 1.3-1.0 Ga.). Thus additional heat from magmatic accretion is unlikely and the metamorphism probably reflects the thermal reponse of the crust to crustal thickening during thrusting.

The gabbros were intruded at around 1200 Ma. and have a continental basaltic character, transitional between tholeiites and alkali basalts. They have notable similarities with other regions of mid-Proterozoic basaltic magmatism in the Canadian shield and taken together, their combined whole rock chemistry is compatible with an extensional setting in the north American craton, prior to collision and crustal thickening in the vicinity of the present Grenville province. The CGB also contains tectonic fragments of anorthositic gneiss which were presumably derived from much larger intrusions. By analogy with research on larger massifs to the northeast (in the Central Granulite terrane and in Labrador), these too were probably intruded in an anorogenic rift environment, thus implying that a large part of the Canadian shield was undergoing extension from ca. 1.5-1.2 Ga.

In the CGB the coronite metagabbros are present as small bodies, ranging in size from a few metres to rarely a kilometre in largest dimension, and typically have tectonic contacts with the enclosing host rocks. They are concentrated in specific clusters and their distribution can be interpreted in terms of map-scale boudinage of former dyke- or sill-like masses during ductile deformation; the metagabbros acting as relatively competent bodies and deforming by failure. As a result the interiors are remarkably well preserved and typically exhibit a subophitic texture, plagioclase lamination and less commonly, primary igneous layering. The primary mineralogy comprises olivine-plagioclase-clinopyroxene-(magnetite-ulvospinel)-ilmenite+biotite+apatite+baddeleyite.

However both olivine and oxides were unstable with calcic plagioclase  $\{An_{50-50}\}$  in the mid to lower crust. This resulted in metastable coronas or reaction rims involving orthopyroxene, clinopyroxene and garnet coupled with the formation of more sodic, spinel-clouded plagioclase  $\{An_{25-42}\}$ . In the least-evolved metagabbros, garnet is present as a garnet-clinopyroxene symplectite where the average, reintegrated bulk Al:Si ratio is directly analogous to the corresponding ratio in spinel-clouded plagioclase. The coronas formed under diffusion-controlled growth and the presence and composition of the symplectite implies that restricted mobility of Al, and to a lesser extent Si, was rate-controlling during corona growth. Furthermore, if a steady state exchange model is applied, uphill Cadiffusion may have been important for restricting entropy production. If applicable, this model further suggests that Mg.Fe had similar mobility with Mg at least as mobile as Ca and probably more so.

Corona-forming reactions were initiated by either slow, subsolidus cooling at depth or by prograde metamorphism. The former is favoured here, whereas more energetic conditions during prograde metamorphism are proposed to be responsible for the subsequent complex and multi-stage textural evolution (Fig. 9.1). This resulted in the variable reconstitution of coronites into garnet amphibolites or two-pyroxene granulites by a combination of deformation, reaction and recrystallisation

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under the important control of varying water activity. Quantitative P,T estimates are equivocal in terms of the initial mode of origin for the coronites, although pressures in the least-evolved samples containing the most sodic spinel-clouded plagioclase, are consistent with intrusion and cooling at around 35-40 Km (9-10 Kbars) in the crust. Furthermore the graphical clinopyroxene thermometer (Lindsley & Anderson, 1983) when applied to the early coronite mineralogy, produces a temperature range of 950-750°C which may reflect "frozen" levels of Ca redistribution during cooling from magmatic temperatures. This variation is substantiated to some extent in that when this thermometer is applied to granulites and reconstituted metagabbros, the results are consistent with the garnetclinopyroxene thermometer of Ellis & Green (1979); i.e 700-750°C. Otherwise P.T estimates in both coronites and evolved metagabbros from gt-cpx. gt-opx and gt-ol-plag thermobarometry, are directly analogous to estimates from assemblages in the host rocks and hence provide an independent test in mafic lithologies, for metamorphism at 8-10 $\pm$ 1-2 Kbars and 700-750+50°C.

Despite the inferred large crustal displacements, there is no marked pressure variation in this part of the CGB, although the pressures may have been approximately 1 Kbar lower to the east and southeast of the area under study, in Opeongo subdomain and in the Kawagama zone. The implication is that both upper amphibolite and granulite facies assemblages equilibrated at around the same P,T conditions but under different fluid activities. Furthermore, although sillimanite is the predominant stable aluminosilicate, the P,T estimates lie just within the kyanite stability field or straddle the Ky-sill boundary. Consequently and as in the coronite metagabbros, temperatures from gt-cpx thermometry probably represent minimum estimates of the peak conditions due to resetting by continuous cation exchange during cooling and uplift. Thus, provided significant crustal displacements took place in the CGB during the period 1.16-1.0 Ga., the cation distribution must have re-equilibrated syn- and post-thrusting.

The earlier history is preserved at least texturally in the coronite metagabbros, garnet peridotites and sapphirine-bearing lithologies. Here a combination of slow reaction kinetics during discontinuous reactions, coupled with low water activity, were responsible for the metastable preservation of assemblages. During uplift, the same controls were also responsible for the safekeeping of metastable granulite and amphibolite

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facies assemblages on their passage to the surface. As in the coronites, restricted mobility of Al was probably important in the genesis of disequilibrium textures in sapphirine-bearing lithologies and testifies to the importance of mineral kinetics in the preservation of complicated reaction histories. When diffusion coefficients are known with sufficient accuracy, mineral zoning and blocking temperatures for different cation exchange reactions in these and other assemblages, coupled with detailed geochronology, may prove to be extremely useful in the detailed reconstruction of P-T-t paths in ancient metamorphic terranes.

FIGURE 9.1: Schematic P-T paths for thrusting in the CGB if P,T estimates are (a) representative of the peak conditions; (b) reset. Symbols I,II and III refer to the proposed stages in the textural evolution of metagabbros (Chapter 6), while ▲ indicates P,T estimates from initial and decompression assemblages in sapphirine-bearing lithologies.



(2) むりょうとう パート・ション

REFERENCES

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- Ackermand, D., Seifert, F., Schreyer, W. (1975), Instability of sapphirine at high pressures. Contrib. Mineral. Petrol. 50, 79-82.
- Ackermand, D., Herd, R.K., Reinhardt, M., Windley, B.F. (1987), Sapphirine parageneses from the Cariba complex, Bahía, Brazil: the influence of Fe<sup>2+</sup>-Fe<sup>3+</sup> distribution on the stability of sapphirine in ntural assemblages. J Meta. Geol. 5, 323-339.
- Anovitz, L.M., Essene, E.J. (1986), Thermobarometry in the Grenville Province, Ontario. Geol. Assoc. Canada program with abstracts, vol 11, p. 41.
- Ashwal, L.D. & Seifert, K.E. (1980), Rare earth element geochemistry of anorthosite and related rocks from the Adirondacks, New York and other massif-type complexes. *Geol. Soc. Amer. Bull.* 91, 105-107.
- Ashwal, L.D. & Wooden, J.L., (1983), Sr and Nd isotope geochronology, geologic history and origin of the adirondack anorthosite. *Geochim. cosmochim. Acta*, 47, 1875–1886.
- Ashworth, J. R. (1986), The role of magmatic reaction, diffusion, and annealing in the evolution of coronitic microstructure in troctolitic gabbro from Risör, Norway: a discussion. *Mineral. Mag.* 50, 469-473.
- Austrheim, H. & Robins, B. (1981), Reactions involving hydration of orthopyroxene in anorthosite-gabbro. Lithos 14, 275-281.
- Baragar, W.R.A. (1977), Volcanism in the stable crust. <u>In</u> Volcanic regimes in Canada, Baragar, W.R.A., Coleman, L.C., Hall, J.L. (Eds.). Geol. Asoc. Canada Special Paper 16, 377-405.
- Barink. H.W. (1984), Replacement of pyroxene by hornblende, isochemically balanced with replacement of plagioclase by garnet, in a metagabbro of upper amphibolite grade. Lithos 17, 247-258.
- Basu, A. R. & Pettingill, H. S., (1983), Origin and age of Adirondack anorthosites re-evaluated with Nd isotopes. Geology, 11, 514-518.

- Bell, K. & Blenkinsop, J., (1980), Whole-rock Rb-Sr studies in the Grenville Province of southeastern Ontario and western Quebec - a summary report. <u>In</u> Current Research, Part C, Geological Survey of Canada, Paper 80-1C, 152-154.
- Beran, A. & Putnis, A. (1983), A model of the OH positions in olivine, derived from infrared-spectroscopic investigations. Phys. Chem. Miner. 9, 57-60.
- Berger, G.W. & York, D. (1981), Geathermometry from 40/39Ar dating experiments. *Geochim. Cosmochim. Acta.* 45, 795-811.
- Bickford, M.E., Van Schmus, W.R., Zeitz, Z (1986), Proterozoic history of the mid-continent region of North America. Geology 14, 492-496.
- Bishop, F.C. & Newton, R.C. (1975), The composition of low-pressure synthetic sapphirine. J. Geol. 83, 511-517.
- Bohlen, S.R & Essene, E.J. (1980), Evaluation of co-existing garnetbiotite, garnet-clinopyroxene and other thermometers in Adirondacks granulites. Geol. Soc. Amer. Bull. 91, 685-719.
- Bohlen, S.R., Valley, J.W., Essene, E.J. (1985), Metamorphism in the Adirondacks I. Petrology, pressure and temperature. J. Petrol. 26, 971-992.
- Bohlen, S.R., Wall, V.J., Boettcher, A.L. (1983a), Experimental investigation and application of garnet granulite equilibria. *Contrib. Mineral. Petrol.* 83, 52-61.
- Bohlen, S.R., Wall, V.J., Boettcher, A.L. (1983b), Geobarometry in Granulites. <u>In</u>: Kinetics and equilibrium in mineral reactions, S.K. Saxena (Ed.). Advances in physical geochemistry Vol 3, chapter 5, 141-171. Springer Verlag.
- Boland, J.N. & Van Roermund, H.L.M. (1983), Mechanisms of exsolution in omphacites from high temperature, Type B, eclogites. Phys. Chem. Minerals 9, 30-37.

- Brady, J. B. (1975), Reference frames and diffusion coefficients. Amer. J. Sci. 275, 954-983.
- Bryan, W.B., Finger, L.W., Chayes, F. (1969), Estimating proportions in petrographic mixing equations by least-squares approximation. Science 163, 926-925.
- Buddington, A.F. (1963), Isograds and the role of H<sub>2</sub>O in metamorphic facies of orthogneisses of the northwest Adirondacks area, New York. Bull. Geol. Soc. Amer. 74, 1155-1182.
- Burt, D.M. (1974), Metasomatic zoning in Ca-Fe-Si exoskarns. <u>In</u> Geochemical Transport and Kinetics, Ed. A.W. Hoffmann et. al, Carnegie Inst. Washington Public. 634, 353pp.
- Carmichael, I.S.E. (1967), The iron-titanium oxides of salic volcanic rocks and their associated ferromagnesian silicates. *Contrib. Mineral. Petrol.* 14, 36-64.
- Cawthorn, R. G., Collerson, K. D. (1974), The recalculation of pyroxene end-member parameters and the estimation of ferrous and ferric iron content from electron microprobe analyses. *Amer. Mineral.* 59, 1203-1208.
- Chatterjee, N.D. & Schreyer, W. (1972), The reaction enstatite + sillimanite = sapphirine + quartz in the system MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>. Contrib. Mineral. Petrol. 36, 49-62.
- Chase, C.G. & Gilmer, T.H. (1973), Precambrian plate tectonics: the Mid-Continent gravity high. Earth Planet. Sci. Lett. 21, 70-78.
- Chesworth, W. (1971), Metamorphic facies series in the Grenville Province Of Ontario. Tectonophysics 14, 71-78.
- Clarke, J.R. & Papike, J.J. (1968), Crystal-chemical characterisation of Omphacite. Contrib. Mineral. Petrol. 67, 17-24.
- Coombs. D.S. & Wilkinson, J.F.G (1969), Lineages and fractionation trends in undersaturated volcanic rocks from the east Otago province (new Zealand) and related rocks. J. Petrol. 10, 440-501.

- Cooper, A. R. (1974), Vector space treatment of multicomponent diffusion. <u>In</u> Geochemical Transport and Kinetics, Ed. A.W. Hoffmann et. al, Carnegie Inst. Washington Public. 634, 353pp.
- Cressey, G, Schmid, R., Wood, B.J. (1978), Thermodynamic properties of almandine-grossular garnet solid solutions. Contrib. Mineral. Petrol. 67, 397-404.
- Culshaw, N.G., Davidson, A., Nadeau, L. (1983), Structural subdivisions of the Grenville Province in the Parry Sound-Algonquin region, Ontario. <u>In</u> Current Research, Part B, Geological Survey of Canada, Paper 83-18, 243-252.
- Davidson, A., (1984), Identification of ductile shear zones in the southwestern Grenville Province of the Canadian Shield. <u>In</u> Kröner, A., & Greiling, R., eds., Precambrian Tectonics Illustrated: E. Schweitzerbart'sche Verlagsbuchhandlung, Stuttgart, 263-279.
- Davidson, A. (1986a), New interpretations in the southwestern Grenville Province. <u>In</u> The Grenville Province, eds. Moore, J. M., Davidson, A., Baer, A. J., Geological Association of Canada Special Paper 31, 61-74.
- Davidson, A. (1986b), Grenville Front relationships near Killarney, Ontario. <u>In</u> The Grenville Province, eds. Moore, J. M., Davidson, A., Baer, A. J., Geological Association of Canada Special Paper 31, 107-117.
- Davidson, A., Morgan, W. C. (1981), Preliminary notes on the geology east of Georgian Bay, Grenville structural province, Ontario. <u>In</u> Current research, Part A. Geological Survey of Canada, Paper 81-1A, 291-298.
- Davidson, A., Grant, S. M. (1986), Reconnaissance geology of western and central Algonquin Park and detailed study of coronitic olivine metagabbro, Central Gneiss Belt, Grenville Province of Ontario. <u>In</u> Current Research, Part B, Geological Survey of Canada, paper 86-18, 837-848.
- Davidson, A., Culshaw, N.G., Nadeau, L. (1982), A tectono-metamorphic framework for part of the Grenville Province, Parry Sound region, Ontario. <u>In</u> Current Research, Part A, Geological Surey of Canada, Paper 82-1A, 175-190.

- Davidson, A., Nadeau, L., Grant, S.M., Pryer, L.L. (1985), Studies in the Grenville Province of Ontario. <u>In</u> Current Research, Part A, Geological Survey of Canada, Paper 85-1A, 463-483.
- Davidson, P.M. & Lindsley, D.H. (1985), Thermodynamic analysis of quadrilateral pyroxenes Part II: model calibration from experiments and applications to geothermometry. *Contrib. Mineral. Petrol.* **91**, 390-404.
- Docka, J.A., Berg, J.H., Klewin, K.W. (1986), Geothermometry in the Kiglapait aureole: Part II. Evaluation of exchange thermometry in a well constrained thermal setting. *J. Petrol.* 27, 605-626.
- Droop, G.T.R. & Bucher Nurminen, K. (1984), Reaction textures and metamorphic evolution of sapphirine-bearing granulites from the Gruf complex, Italian Central Alps. J. Petrol. 25, 766-803.
- and metamorphic evolution of sapphirine-bearing granulites from the Gruf complex, Italian Central Alps. J. Petrol. 25, 766-803.
  - Eade, R.E. & Fahrig, W.F. (1973), Geochemical evolutionary trends of continental abundances of some trace elements in the Canadian Shield. Geol, Surv. Canada paper 72-46.
  - Ellis, D.J. & Green, D.H. (1979), An experimental study of the effect of Ca upon the garnet-clinopyroxene Fe-Mg exchange equilibria. *Contrib. Mineral. Petrol.* 71, 13-22.
  - Ellis, D.J. & Green, D.H. (1985), Garnet-forming reactions in mafic granulites from Enderby Land, Antarctica - Implications for geothermometry and geobarometry. J. Petrol. 26, 633-662.
  - Emmet, T.F. (1982), The petrography and geochemistry of corona-bearing dolerite from the Jotun nappe, central southern Norway. *Mineral. Mag.* 46, 43-48.
  - Emslie, R.F. (1978), Anorthosite massifs, rapakivi granites and late Proterozoic rifting of N. America. *Precambrian Res.* 7, 61-98.
  - Emslie, R.F. (1983), The coronitic Michael gabbros, Labrador: Assessment of Grenvillian metamorphism in NE Grenville province. Current Research part A, Geol. Surv. Canada 83-1A, 139-145.

- Engel, A.E.J. & Engel, C.E. (1952), Progressive metamorphism of amphibolite, northwest Adirondack mountains, New York. Bull. Geol. Soc. Amer., A.F. Buddington volume, 37-82.
- England, P.C. & Thompson, A.B. (1984), Pressure-temperature-time path of regional metamorphism I. Heat transfer during the evolution of regions of thickened continental crust. J. Petrol. 25, 894-928.
- England, R.N. (1974), Corona structures formed by near-isochemical reaction between olivine and plagioclase in a metamorphosed dolerite. *Min. Mag.* **39.** 816-818.
- Esbensen, K.H. (1978), Coronites from the Fongen gabbro complex, Trondheim Region, Norway: role of water in the olivine-plagioclase reaction. N. Jb. Mineral. Abh. 132, 113-135.
- Essene, E.J. (1982), Geologic thermometry and barometry. <u>In</u> Characterization of metamorphism through mineral equilibria, Ferry, J.M. (Ed.). Reviews in Mineralogy 10, 153-206.
- Ferry, D.M. & Burt, D.M. (1982), Characterization of metamorphic fluid Composition through mineral equilibria. <u>In</u> Characterization of metamorphism through mineral equilibria, Ferry, J.M. (Ed.). Reviews in Mineralogy 10, 207-262.
- Ferry, D.M. & Spear, F.S. (1978), Experimental calibration of the partitioning of Fe and Mg between biotite and garnet. Contrib. Mineral. Petrol. 66, 113-117.
- Fisher, G.W. {1973}, Non-equilibrium thermodynamics as a model for diffusion controlled metamorphic processes. Amer. J. Sci. 273, pp 897-924.
- Fisher, G.W. (1977). Nonequilibrium thermodynamics in metamorphism: <u>In</u> Thermodynamics in Geology, Ed. D. G. Fraser, pp 381-403. D. Reidal Pub. Co., Dordrecht, Holland, 410pp.
- Foster, C. T. (1981), A thermodynamic model of mineral segregations in the lower sillimanite zone near Rangely, Maine. Amer. Mineral. 56, 260-277.

- Frodesen, H. (1968), Coronas around olivine in a small gabbro intrusion, Bamble area, South Norway. Norsk. Geol. Tidsskr. 88, 201-206.
- Ganguly, J. (1973), Activity-composition relation of jadeite in omphacite pyroxene. *Earth Planet. Sci. Lett.* 19, 145-153.
- Ganguly, J. & Kennedy, G.C. (1974), The energetics of natural garnet solution I. Mixing of the aluminosilicate end-members. *Contrib. Mineral. Petrol.* 48, 137-148.
- Ganguly, J. & Saxena, S. (1984), Mixing properties of aluminosilicate garnets: constraints from natural and experimental data, and application to geobarometry. *Amer. Mineral.* **69**, 88-91.
- Gardner, P.M. & Robins, B. (1974), The olivine-plagioclase reaction: Geological evidence from the Seiland petrographic province, Northern Norway. Contrib. Mineral. Petrol. 44, 149-156.
- Gasparik, T. (1987), Orthopyroxene thermobarometry in simple and complex systems. Contrib. Mineral. Petrol. 96, 357-370.
- Gasparik, T. & Newton, R.C. (1984), The reversed alumina content of orthopyroxene in equilibrium with spinel and forsterite in the system MgO-Al<sub>2</sub>O<sub>2</sub>-SiO<sub>2</sub>. Contrib. Mineral. Petrol. 85, 186-196.
- Glassley, W.L. & Sorenson, K. (1980), Constant P -T amphibolite to granulite facies transition in Agto (W. Greenland) metadolerites: implications and applications. J. Petrol. 21, 69-105.
- Graham, C.M. & Powell, R. (1984), A garnet-hornblende thermometer: calibration, testing and application to the Pelona schist, southern California. J. Meta. Geol. 2, 13-31.
- Grant, J. A. (1977). Crystallographic projection of chemical potential relationships as an aid in the interpretation of metasomatic zoning. *Amer. Mineral.* 62, 1012-1017.
- Grant, S.M. (in press), Diffusion models for corona formation in metagabbros from the western Grenville Province, Ontario. Submitted to *Contrib. Mineral. Petrol.*

- Greenwood, H.J. (1967), The N-dimensional tie-line problem. Geochim. Cosmochim. Acta. 31, 465-490.
- Greenwood, H.J. (1975), Buffering of pore fluids by metamorphic reactions. Amer. J. Sci. 275, 573-593.
- Gresens. R. L. (1967), Composition-volume relationships of metasomatism. Chem. Geol. 2, 47-65.
- Grieve, R. A. F., Gittins, J. (1975), Composition and formation of coronas in the Hadlington Gabbro, Ontario, Canada. Can. J. Ear. Sci. 12, 289-299.
- Griffin, W.L. (1971), Genesis of coronas in Anorthosites of the upper Jotun nappe, Indre Sogn, Norway, *J. Petrol.* 12, 219-243.
- Griffin, W.L. (1972), Formation of eclogites and the coronas in anorthosites, Bergen Arcs, Norway. Geol. Soc. Amer. Memoir 135, 37-63.
- Griffin, W. L., Heier, K. S. (1973), Petrological implications of some Corona structures. Lithos 6, 315-335.
- Griffin, W.L., Mellini, M., Oberti, R.,Rossi, G.(1985), Evolution of Coronas in Norwegian anorthosites: reevaluation based on crystal chemistry and microstructures. *Contrib. Mineral. Petrol.* **91**, 330-339.
- Griffin, W.L. & Raheim, A. (1973), Convergent metamorphism of eclogites and dolerites, Kristiansund area, Norway. Lithos 6, 21-40.
- Guidotti. C.V. (1982), Micas in metamorphic rocks. <u>In</u> Micas, Bailey, S.W. (Ed.), Reviews in Mineralogy 13, 357-468.
- Hamner, S.K. & Ciesielski, A. (1984). Structural reconnaissance of the northwest boundary of the Central Metasedimentary Belt, Gernville Province; Current Research, Part B, Geol. Surv. Canada, paper 84-18, 121-131.
- Harley, S.L. (1984a). An experimental study of the partitiioning of Fe and Mg between garnet and orthopyroxene. Contrib. Mineral. Petrol. 86, 359-373.

- Harley, S.L. (1984b), The solubility of alumina in orthopyroxene coexisting with garnet in FeO-MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> and CaO-FeO-MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>. J. Petrol. 25, 665-696.
- Harley, S.L. & Green, D.H. (1982), Garnet-orthopyroxene barometry fro granulites and peridotites. *Nature* **300**, 697-712.
- Herd. R.K., Ackermand, D., Windley, B.F., Rondot, J. (1986). Sapphirinegarnet rocks, St. Maurice area, Quebec: petrology and implications for tectonics and metamorphism. <u>In</u> The Grenville Province, eds. Moore, J. M., Davidson, A., Baer, A. J., Geological Association of Canada Special Paper 31, 241-253.
- Higgins, J.B., Ribbe, P.H. Herd, R.K. (1979), Sapphirine I crystal chemical contributions. *Contrib. Mineral. Petrol.* 68, 349-356.
- Hodges, K.V. & Spear, F.S. (1982), Geothermometry, barometry and the Al<sub>2</sub>SiO<sub>5</sub> triple point at Mt. Moosiluke, New Hampshire. Amer. Mineral. 67, 1118-1134.
- Holdaway, M.J. (1971), Stability of andalusite and the aluminosilicate phase diagram. *Amer. J. Sci.* 271, 97-131.
- Holm, P.E., Grant, B.D., Gerasimoff, M.D., Huaung, C.H, Smith, T.E. (1983), Ocean floor basalt affinity of a Grenville metavolcanics sequence. Geol. Soc. Amer. Abst with programs 15, 598.
- Indares, A. & Martignole, J. (1985), Biotite-garnet geothermometry in the granulite facies. The significance of Ti and Al in biotite. Amer. Mineral. 70, 272-278.
- Irving. E. & Baragar, W.R.A. (1971), A guide to the chemical classification of the common volcanic rocks. *Can. J. Earth Sci.* 5, 523-548.
- Jan, M.Q., Parvez, M.K., Khattak, M.U.K. (1984), Coronites from the Chilas and Jijal-Patan complexes of Kohistan. Geol. Bull. Univ. Peshawar 17, 75-85.
- Joesten, R. (1977), Evolution of mineral assemblage zoning in diffusion metasomatism. *Geochim. Cosmochim. Acta* 41, 649-670.

- Joesten, R. (1978), Diffussion-controlled growth of pyroxene-spinel coronas between forsterite and anorthite in the system CaO-MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>. Geol. Soc. Amer. Abstr Program 10, 429.
- Joesten, R. (1985), Course notes Mechanisms of Reaction Workshop. Imperial College, London.
- Joesten, R. (1986a), The role of magmatic reaction, diffusion and annealing in the evolution of coronitic microstructures in troctolitic gabbro from Risor, Norway. *Mineral. Mag.* 50, 441-467.

Joesten, R. (1986b), Reply. Mineral. Mag. 50, 474-479.

- Johansson, L. & Möller, C. (1986), Formation of sapphirine during retrogression of a basic high pressure granulite, Roan, Western Gneiss Region, Norway. Contrib. Mineral. Petrol. 94, 29-41.
- Johnson, C.A., Bohlen, S.R., Essene, E.J. (1983), An evaluation of garnetclinopyroxene geothermometry in granulites. *Contrib. Mineral. Petrol.* 84, 191-198.
- Johnson, C.A. & Essene, E.J. (1982), The formation of garnet in olivinebearing metagabbros from the Adirondacks. *Contrib. Mineral. Petrol.* 81, 240-251.
- Katchalsky, A., Curran, P. F. (1965), Nonequilibrium Thermodynamics in Biophysics: Harvard Univ. Press, Cambridge, MA, 248pp.
- Kerrich, M.A. & Thomas, A. (1986), Sapphirine-bearing paragneiss from the northern Grenville Province in Labrador, Canada: protolith composition and metamorphic P-T conditions. *Geology* 14, 844-847.
- Korzhinskii, D. S. (1959), Physio-chemical basis of the paragenesis of minerals. New York Consultants Bureau, Inc. 142pp.
- Kretz, R. (1982), Transfer and exchange equilibria in a portion of the pyroxene quadrilateral as deduced from natural and experimental data. Geochim. Cosmochim. Acta. 46, 411-421.

- Krogh, T. E. & Davis, G. L., (1967), Geochronology of the Grenville Province. <u>In</u> Carnegie Institution of Washington Yearbook 67, 224-230.
- Krogh, T. E., & Wardle, R., (1984), U-Pb isotopic ages along the Grenville Front. Geological Association of Canada - Mineralgical Association of Canada Program with abstracts, V. 9, page 80.
- Laird, J. (1980), Phase equilibria in mafic schists from Vermont. J. Petrol. 21, 1-37.
- Lal, R.K., Ackermand, D., Seifert, F., Haldar, S.K. (1978), Chemographic relationships in sapphirine-bearing rocks from Sonapahar, Assam, India. Contrib. Mineral. Petrol. 67, 169-187.
- Lal. R.K., Ackermand, D., Raith, M., Raase, P., Seifert, F. (1984), Sapphirine-bearing assemblages from Kiranur, southern India: a study of Chemographic relationships in the Na<sub>2</sub>O-FeO-MgO-Al<sub>2</sub>O<sub>3</sub>-H<sub>2</sub>O system. Neues. Jahrbuch. Mineral. Abh. 150, 121-152.
- Landergren, S. (1978). Vanadium, <u>In</u> Handbook of Geochemistry II/2, Wedepohl, K.H. (Ed.), chapter 23, D-1 to F-6.
- Leake, (1978), Nomenclature of amphiboles. Amer. Mineral. 63, 1023-1052.
- Lindsley, D.H. (1983), Pyroxene thermometry. Amer. Mineral. 58, 477-493.
- Lindsley, D.H. & Anderson, D.J. (1983), A two-pyroxene thermometer. Proc. 13th Lunar Planet. Sci. Conf. J. Geophy. Res. Suppl. 88, A887-A906.
- Loomis, T.P. (1977), Kinetics of a garnet granulite reaction. Contrib. Mineral. Petrol. 62, 1-22.
- MacDonald, G.A. & Katsura, T. (1964), Chemical composition of Hawaiian lavas. J. Petrol. 5, 82-133.
- Marsh, N.G. (1981-85), Notes on sample preparation, University of Leicester geology department, Leicester, U.K.
- Mason, R. (1967), Electron probe microanalysis of coronas in a troctolite from Sulitjelma, Norway. *Mineral. Mag.* 36, 504-514.

- McLelland, J. M., Whitney, P. R. (1980), Compositional controls on spinel clouding and garnet formation in plagioclase of olivine metagabbros, Adirondack Mountains, New York. *Contrib. Mineral. Petrol.* 73, 243-251.
- Medaris, L.G. (1969), Partitioning of Fe<sup>2+</sup> and Mg<sup>2+</sup> between coexisting synthetic olivine and orthopyroxene. Amer. J. Sci. 267, 945-968.
- Mereu, R. F., Wang, D., Kuhn, O. (1986), Evidence for an inactive rift in the Precambrian from a wide-angle reflection survey across the Ottawa-Bonnechere Graben. <u>In</u> Reflection Seismology: The continental crust. Barazangi, M., Brown, L. (Eds.). Geodynamics Series, vol 14, 127-134, Amer. Geoph. Union.
- Meyers. R.E. & Emslie, R.F. (1977), The Harp dikes and their relationship to the Helikian geological record in Central Labrador. *Can. J. Earth* Sci. 14, 2683-2696.
- Miller, C. (1974), Reaction rim between olivine and plagioclase in metaperidotite, Otztal Alps, Austria. Contrib. Mineral. Petrol. 43, 333-342.
- Mohan, A., Ackermand, D., Lal, R.K. (1986), Reaction textures and P-T-X trajectory in the sapphirine-spinel-bearing granulite from Ganguvarpatti, southern India. Neues Jahrbuch Mineral. Abh. 154, 1-19.
- Mongkoltip, P., Ashworth, J. R. (1983), Guantitative estimates of an open-system symplectite forming reaction: restrcted diffusion of Al and Si in coronas around olivine. J. Petrol. 24, 635-661.
- Mørk. M.B.E. (1985), Incomplete P-T metamorphic transition within the Kvamsøy pyroxenite complex, west Norway: a study of disequilibrium. J Meta. Geol. 3, 245-264.
- Mørk, M.B.E. (1986), Coronite and eclogite formation in olivine gabbro (western Norway): reaction paths and garnet zoning. *Hin. Mag.* 50, 417-426.
- Morse, S.A. (1982), A partisan view of Proterozoic anorthosite. Amer. Miner1. 67, 1087-1100.

- Mueller, P.A. & Rogers, J.J.W. (1973), Secular chemical variation in a series of Precambrian mafic rocks, Beartooth Mtns., Montana and Wyoming. Bull. Geol. Soc. Amer. 84, 3645-3652.
- Murthy, M. V. N. (1958), Coronites from India and their bearing on the origin of coronas. Geol. Soc. Amer. Bull. 69, 23-38.
- Nadeau, L. (1985), Characterization of lithotectonic units and their boundaries in the Huntsville region, Central Gneiss Belt. <u>In</u> Davidson et al. (1985), Studies in the Grenville Province of Ontario. <u>In</u> Current Research, Part A, Geological Survey of Canada, Paper 85-1A, 463-483.
- Newton, R.C. (1983), Geobarometry of high-grade metamorphic rocks. Amer. J. Sci. 283-A, 1-28.
- Newton, R.C. & Haselton, H.T. (1981), Thermodynamics of the Gt-Plag-Al<sub>2</sub>SiO<sub>5</sub>-Qtz geobarometer. <u>In</u> Thermodynamics of minerals and melts, R.C. Newton et al. (Eds.), 131-147. Springer-Verlag, New York.
- Newton, R.C. & Perkins, D. (1982), Thermodynamic calibration of geobarometers based on the assemblage garnet-plagioclase-orthopyroxene (clinopyroxene)-quartz. Amer. Mineral. 67, 203-222.
- Newton, R.C., Smith, J.V., Windley, B.F. (1980), Carbonic metamorphism, granulites and crustal growth. *Nature* 288, 45-49.
- Nishiyama, T. (1983), Steady diffusion model for olivine-plagioclase corona growth. Geochim Cosmochim. Acta 47, 283-294.
- O'Neill, H. St. C. (1981), The transition between spinel lherzolite and garnet lherzolite, and its use as a geobarometer. *Contrib. Mineral. Petrol.* 77, 185-194.
- Orville, P.M. (1972), Plagioclase cation exchange equilibria with aqueous chloride solutions at 700°C and 2000 bars pressure in the presence of quartz. Amer. J. Sci. 272, 234-272.
- Otten, M.T. (1984), Na-Al-rich gedrite coexisting with hornblende in a Corona between plagioclase and olivine. Amer. Min. 69, 458-464.

- Palmer, H.C., Mez, B.A., Hayatsu, H. (1977), The Sudbury dikes of the Grenville Front region: paleomagnetism, petrochemistry and K-Ar age studies. Can J. Earth Sci. 14, 1867-1887.
- Papike, J.J., Cameron, K. L., Baldwin, K. (1974), Amphiboles and pyroxenes: charaterization of other than quadrilateral components and estimates of ferric iron from microprobe data. Geol. Soc. Amer Program with abstracts, vol. 6, 1053-1054.
- Pearce, J.A. (1983), Role of the sub-continental lithosphere in magma genesis at active continental margins. <u>In</u> Continenetal basalts and mantle xenoliths, Hawkesworth, C.J. & Norry, M.J. (Eds.): Nantwich, Shiva, 230-249.
- Perkins, D. (1979), Application of new thermodynamic data to mineral equilibria. Unpublished Ph. D. thesis, University of Michigan, Ann Arbor, Michigan.
- Perkins, D. & Chipera, S.J. (1985), Garnet-orthopyroxene-plagioclase-quartz barometry: refinement and application to the English River Subprovince and the Minnesota River valley. Contrib. Mineral. Petrol. 89, 68-80.
- Perkins, D. Westrum, E.F., Essene, E.J. (1980), Thermodynamic properties and phase relations of some minerals in the system  $CaO-Al_2O_3-SiO_2-H_2O$ . Geochim. Cosmochim. Acta. 44, 61-84.
- Pillar, J.E. (1985), Geochemistry of high grade gneisses, with examples from west Greenland and British Columbia. Unpublished Ph.D. Thesis, University of Leicester, Leicester, U.K.
- Powell, R. (1985), Geothermometry and geobarometry: a discussion. J. Geol. Soc. Lond. 142, 29-38.
- Powell, R. & Powell, M. (1977), Geothermometry and oxygen barometry using coexisting iron-titanium oxides: a reappraisal. Min. Mag. 41, 257-263.
- Pouchou, J.C. & Pichoir, F. (1984), A new model for quantitative X-ray microanalysis Part I: application to the analysis of homogeneous samples. La Recherch Aérospatiale no. 3, 13-38.
- Raheim, A. & Green, D.H. (1974), Experimental determination of the temperature and pressure dependence of Fe-Mg partition coefficients for coexisting garnet and clinopyroxene. Contrib. Mineral. Petrol. 48, 179-203.
- Reid, M.J., Gancave, A.J., Lee, A.L. (1973), Constrained least squares analysis of petrologic problems with an application to lunar sample 12040. Earth Planet. Sci. Lett. 17, 433-445.
- Reynolds, R.C. & Frederickson, A.F. (1962), Corona development in Norwegian hyperites and its bearing on the metamorphic facies concept. Bull. Geol. Soc. Amer. 73, 59-72.
- Rice, J.M. & Ferry, J.M. (1982), Buffering, infiltration and the control of intenive variables during metamorphism. <u>In</u> Characterization of metamorphism through mineral equilibria, Ferry, J.M. (Ed.). Reviews in Mineralogy 10, 263-326.
- Rickwood, P. C. (1968), On recasting analyses of garnet into end member molecules. *Contrib. Mineral. Petrol.* 18, 175-198.
- Rivers, T. (1983), The northern margin of the Grenville Province in western Labrador – anatomy of an ancient orogenic front. *Precambrian Res.* 22, 41-73.
- Rivers, T. (1985) Granulite and amphibolite facies coronas in the Grenville Province of western Labrador. Geol. Assoc. Canada program with abstracts, vol. 11, p 119.
- Robie, R. A., Hemingway, B.S., Fisher, J. R. (1981), Thermodynamic properties of minerals and related substances at 298.15 K and 1 bar (10<sup>5</sup> pascals) pressure and at higher temperatures. U.S. Geol. Surv. Bull. 1452, 465pp.
- Ross. M. & Huebner, J.S. (1979), Temperature-composition relationships between naturally occurring augite, pigeonite and orthopyroxene at one bar pressure. Amer. Mineral. 64, 1133-1155.

- Rubie, D.C. (1985), The catalysis of mineral reactions by water and restrictions on the presence of aqueous fluid during metamorphism. *Minerl. Mag.* 50, 399-415.
- Rumble, D. (1976), The use of mineral solid solutions to measure chemical potential gradients in rocks. Amer. Mineral. 61, 1167-1174.
- Ryburn, R. J., Raheim, A., Green, D. H. (1976), Determination of the P,T paths of natural eclogites during metamorphism - record of subduction. Lithos 9, 161-164.
- Sack. R.O. (1980a), Adirondacks mafic granulites and a model lower crust: summary. Bull Geol. Soc. Amer. 91, part I, 89-93.
- Sack, R.O. (1980b), Adirondacks mafic granulites and a model lower crust. Bull Geol. Soc. Amer. 91, part II (microfiche), 349-442.
- Sapountzis, E.S. (1975), Coronas from the Thesaloniki gabbros, (North Greece). Contrib. Mineral. Petrol. 51, 197-203.
- Saxena, S.K., Sykes, J., Eriksson, G. (1986), Phase equilibria in the pyroxene quadrilateral. J. Petrol. 27, 843-852.
- Schau, M., Davidson, A., Carmichael, D.M. (1986), Granulites and granulites. GAC Fieldtrip Guidebook No. 6, Geol. Assoc. Canada, 36pp.
- Schärer, U., Krogh, T. E., Gower, C. F. (1986). Age and evolution of the Grenville Province in eastern Labrador from U-Pb systematics in accessory minerals. *Contrib. Mineral. Petrol.* 94, 438-451.
- Schreyer, W. & Seifert, F. (1969), Compatability relations of aluminium in the system MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>-H<sub>2</sub>O and K<sub>2</sub>O-MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>-H<sub>2</sub>O at high pressures. Amer. J. Sci. 267, 371-388.
- Schwerdtner, W. M., Mawer, C. K., (1982), Geology of the Gravenhurst region, Grenville structural Province, Ontario. <u>In</u> Current Research, Part B, Geological Survey of Canada, Paper 82-1B, 195-207.
- Seifert, F. (1974), Stablility of sapphirine: a study of the aluminous part of the system MgO-Al<sub>2</sub>O<sub>2</sub>-SiO<sub>2</sub>-H<sub>2</sub>O. J. Geology 82, 173-204.

- Sen, S.K. & Bhattacharaya, A. (1984), An opx-gt thermometer and its applicatin to the Medaris charnockites. Contrib. Mineral. Petrol. 88, 64-71.
- Sheraton, J.W. & Black, L.P. (1981), Geochemistry and geochronology of Proterozoic tholeiite dykes of east Antarctica: evidence for mantle metasomatism. Contrib. Mineral. Petrol. 78, 305-317.
- Sills, J.D., Ackermand, A., Herd, R.K, Windley, B.F. (1983), Bulk composition and mineral parageneses of sapphirine-bearing rocks along a gabbro-lherzolite contact at Finero, Ivrea zone, N. Italy. J. Meta. Geol. 1, 337-351.
- Silver, L.T. (1969), A geochronologic investigation of the anorthosite complex, Adirondack Mountains, New York. <u>In</u> Isachsen, Y.W. (Ed.) Origin Of anorthosites and related rocks. New York State Museum and Science Memoir 18, 233-252.
- Silver, L. T., Lumbers, S. B., (1966), Geochronologic studies in the Bancroft-Madoc area of the Grenville Province, Ontario. Abst. Geological Society of America Special Publication 87, p. 156.
- Spear, F.S. (1982), Phase equilibria of amphibolites from the Post Pond Volcanics, Mt. Cube Quadrangle, Vermont. J. Petrol. 23, 383-426.
- Spear, F.S., Rumble, D., Ferry, J.M. (1982a), Linear algebraic manipulation of N-dimensional composition space. <u>In</u> Characterization of metamorphism through mineral equilibria, Ferry, J.M. (Ed.). Reviews in Mineralogy 10, 53-104.
- Spear, F.S., Ferry, J.M, Rumble, D. (1982b), Analytical formulation of phase equilibria: the Gibb's method. <u>In</u> Characterization of metamorphism through mineral equilibria, Ferry, J.M. (Ed.). Reviews in Mineralogy 10, 105-152.
- Starmer, I.C. (1969), Basic plutonic intrusions of the Risör-Sondeled area, south Norway: the original lithologies and their metamorphism. Norsk. geol. tidsskr. 49, 403-431.

- Stockwell, C. H. (1982), Proposals for time classification and correlation of Precambrian rocks and events in Canada and adjacent areas of the Canadian Shield; Part 1: A time classification of Precambrian rocks and events. Geological survey of canada, Paper 80-19, 139pp.
- Thompson, A.B. (1983), Fluid-absent metamorphism. J. Geol. Soc. Lond. 140, 533-547.
- Thompson, A.B. & England, P.C. (1984), Pressure-temperature-time path of regional metamorphism II. Their inferences and interpretation using mineral assemblages in metamorphic rocks. J. Petrol. 25, 929-955.
- Thompson, J.B., Jr. (1959), Local equilibrium in metasomatic processes: <u>In</u> Researches in Geochemistry, Ed. P. H. Abelson, Vol. 1, 427-457. Wiley, New York, 511pp.
- Thompson, J.B., (1982), Composition space: an Algebraic and geometric approach. <u>In</u> Characterization of metamorphism through mineral equilibria, Ferry, J.M. (Ed.). Reviews in Mineralogy 10, 1-31.
- Thompson, R.N., Morrison, M.A., Dickin, A.P., Hendry, G.L. (1983), Continental flood basalts.... Arachnids rule O.K.? <u>In</u> Continenetal basalts and mantle xenoliths, Hawkesworth, C.J. & Norry, M.J. (Eds.), 158-185. Nantwich, Shiva.
- Tracy, R. J., McLellan, E. L. (1985), A natural example of the kinetic controls of composition and textural equilibration. <u>In</u> Metamorphic reactions: kinetics, texture and deformation. Ed. A. B. Thomson & D.C. Rubie. Advances in Physical Geochemistry vol. 4, Springer-Verlag 291pp.
- Turner, F.J. (1981), Metamorphic petrology: Mineralogical, field and tectonic aspects. 2nd Addition, McGraw-Hill, 524pp.
- Upton, B.G.J. & Thomas, J.E. (1980), The Tututoq Younger Giant Dyke Complex, south Greenland: Fractional crystallisation of transitional Olivine basalt magma. J. Petrol. 21, 167-198.
- Valley, J.W. (1985), Polymetamorphism in the Adirondacks: wollastonite at the contact of shallowly intruded anorthosite. <u>In</u> Touret, J.L. (Ed.) The deep proterozoic crust in the North Atlantic provinces. Reidel.

- Valley, J.W, O'Neill, J.R. (1982), Oxygen isotope evidence for shallow emplacement of Adirondack anorthosite. Nature, 300, 487-500.
- Van Breemen, O. & Upton, B.G.J. (1972), The age of some Gardar intrusive complexes, south Greenland. Bull. Geol. Soc. Amer. 83, 3381-3390.
- Van Breemen, O., Davidson, A., Loveridge, W. D., Sullivan, R. W., (1988),
  U-Pb zircon geochronology of Grenville tectonites, granulites and igneous precursors, Parry sound, Ontario. <u>In</u> The Grenville province,
  Moore, J. M., Davidson, A., Baer, A. J. (Eds.), Geological Association of canada, Special paper 31, 191-207.
- Van Lamoen, H. (1979), Coronas in olivine gabbros and iron ores from Susimäki and Riuttamaa, Finland. Contrib. Mineral. petrol. 68, 259-268.
- Van Schmus, W. R. (1965), The geochronology of the Blind River Bruce Mines area, Ontario, Canada. Journal of Geology, v. 73, 755-780.
- Van Schmus, W. R., Bickford, M. E., (1981), Proterozoic chronology and evolution of the midcontinent region, North America. <u>In</u> Kröner, A., ed., Precambrian Plate Tectonics: Elsevier, Amsterdam, 261-196.
- Wardle, R.J., Rivers, T., Gower, C.F., Nunn, G.A.G., Thomas, A. (1986), The northeastern Grenville province: new insights. <u>In</u> The Grenville province Moore, J. M., Davidson, A., Baer, A. J. (Eds.), Geological Association of canada, Special paper 31, 13-29.
- Weaver, B.L. & Tarney, J. (1983), Chemistry of the sub-continental mantle: inferences from Archaean and Proterozoic dykes and continental flood basalts. <u>In</u> Continenetal basalts and mantle xenoliths, Hawkesworth, C.J. & Norry, M.J. (Eds.): Nantwich, Shiva, 111-138.
- Wells, P.R.A. (1979), P-T conditions in the Moines of central Scotland. J. Geol. Soc. London 136, 663-671.
- Whitney, P.R., McLelland, J. M. (1973). Origin of coronas in metagabbros of the Adirondack Mts., N.Y. Contrib. Mineral. Petrol. 39, 81-98.

- Whitney, P.R. & McLelland, J.M. (1983), Origin of biotite-hornblende-garnet coronas between oxides and plagioclase in olivine metagabbros, Adirondack region, New York. Contrib. Mineral. Petrol. 82, 34-41.
- Wiebe, R.A. (1985), Proterozoic basalt dikes in the Nain anorthosite complex, Labrador. *Can. J. Earth Sci.* 22, 1149-1157.
- Wiebe, R.A. (1986), lower crustal cumulate nodules in Proterozoic dykes of the Nain complex: evidence for the origin of Proterozoic anorthosites. J. Petrol. 27, 1253-1275.
- Williams, C.T. (1978), Uranium-enriched minerals in mesostasis areas of the Rhum layered pluton. *Contrib. Mineral. Petrol.* 56, 29-39.
- Windley, B.F. (1986), Comparative tectonics of the western Grenville and the western Himalaya. <u>In</u> The Grenville Province, Moore, J.M., Davidson, A., Baer, A.J. (Eds.), Geol. Assoc. of Canada, Special Paper 31, 341-348.
- Wood, B.J. (1975), The influence of pressure, temperature and bulk composition on the appearance of garnet in orthogneisses - an example from South Harris, Scotland, Earth Planet. Sci. Lett. 26, 299-311.
- Wood, D.A., Joron, J-L., Treuil, M., Norry, M.J., Tarney, J. (1979), Elemental and Sr isotope variation in basic lavas from Iceland and the surrounding ocean floor: the nature of mantle source heterogeneities. *Contrib. Mineral. Petrol.* 70, 319-339.
- Wynne-Edwards, H. R., (1972), The Grenville Province. <u>In</u> Price, R. A., Douglas, R. J. W., eds., Variations in Tectonic Styles in Canada: Geological Association of Canada, Special Paper 11, 263-334.
- Yakowitz, H., Myklebust, R.L., Heinrich, K.F.J. (1974), FRAME: an on-line correction procedure for quantitative electron probe microanalysis. NBS Technical note 796, 46pp.
- Yardley, B.W.D. & Baltatzis, E. (1985), Retrogression of staurolite schists and the sources of infiltrating fluids during metamorphism. Contrib. Mineral. petrol. 89, 59-68.

Yund, R.A. & McCallister, R.H. (1970), Kinetics and mechanisms of exsolution. Chem. Geol. 6, 5-30. APPENDICES

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The following abbreviations have been adopted for mineral compositions and end-member phase components.

MINERAL ABBREVIATIONS:	
Gt – garnet	Zois - zoisite
Opx – orthopyroxene	Sph - sphene
Cpx – clinopyroxene	Sill - sillimanite
Ol - olivine	Ky – kyanite
Plag(Pl) - plagioclase	Alsil - aluminosilicate (unspecified)
Op - opaque oxides (unspecified)	Wo – wollastonite
Sp-Pl - spinel-clouded plagioclase	Ilm - ilmenite
Mt-Usp – magnetite-ulvospinel	Scap – scapolite
Amph - amphibole (unspecified)	Rut - rutile
Hbl - hornblende	Cor - corundum
Sym - symplectite	Spin (Sp) - spinel
Prim cpx – primary clinopyroxene	Sapp (Sa) - sapphirine
Kfsp - alkali feldspar	Carb - carbonate alteration
Qtz - quartz	Musc - muscovite
Ap - apatite	Chl - chlorit <del>e</del>
Zr - zircon	Epid - epidote
8add - baddeleyite	Ves - vesuvianite
Phlog - phlogopite	Cc - calcite
Biot(Bi) - biotite	Graph - graphite

END-MEMBER PHASE COMPOSITIONS:
Gr - grossular
Alm - almandine
Pyr - pyrope
And - andradite
Sp – spessartine
CaTs - Ca-tschermaks CaAl <sub>2</sub> SiO <sub>8</sub>
Jd - jadeite NaAlSi <sub>2</sub> 0 <sub>6</sub>
Di - diopside
Hed - hedenbergite
En - enstatite
Fs - ferrosilite
Wo - wollastonite

Fa - fayalite
Fo - forsterite
An - anorthite
Ab - albite
Or - orthoclase
Parg - pargasite NaCa_Mg_AlSi_Al_0_(OH)
Ts - tschermakite Ca2Mg3A12Si6A12022(OH)2
Eden - edenite NaCa Mg AlSi 02 (OH)
Trem - tremolite Ca Mg Sig 0 (OH)
Mt – magnetite
Usp - ulvospinel

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In the sample directory which follows the samples are sub-divided into four categories: 1} coronite metagabbros and related rocks; 2) Undifferentiated amphibolite facies gneiss, granulite, mafic and ultramafic rock; 3) Anorthosites, leucogabbros and associated mafic rocks; 4) Sapphirine-bearing assemblages.

ABBREVIATIONS: WD - wavelength dispersive analyses; ED - energy dispersive; LEIC/CGS - whole rock analyses from Leicester plus duplicate analyses and Fe2/Fe3 determinations by the Canadian Geological Survey. LEIC - whole rock determinations at Leicester only.

#### 1) METAGABBROS

GO HOME SUBDOMAIN						
SAMPLE	MINERALOGY	PROBE	WHOLE ROCK	GRID REFERENCE/COMMENTS		
86DMS-18	Coronite	WD: ol,opx,cpx,gt, sym,sp-pl		Central part of main intrusion GR [59600E 496315N]		
850MC_C	• • • •	ED: Ilm,bi,amph				
9-61069	Loronite	WO: Sp-pl.sym ED: Ol.opx.cpx.gt, plag.amph	LEIC/CGS	Amph-bearing coronas around UI GR [ <u>5</u> 9720E <u>49</u> 6320N]		
85DMS-7	Coronite	WD: ol;opx;cpx;sym gt;sp-pl	LEIC/CGS	Spinel-opaque exide intergrowth GR [ <u>5</u> 9615E <u>49</u> 6305N]		
85DMS-8	Coronite	WD: ol,opx,cpx,sym gt,sp-pl	LEIC/CGS	GR ( <u>5</u> 9540E <u>49</u> 6285N)		
84DMS-13A	Coronite	WD: ol,opx,cpx,amph sym,gt,sp-pl,ilm Ti-amph.bi.plag	, LEIC/CGS ,	Amph-bearing coronas around Ol GR [ <u>5</u> 9630E <u>49</u> 6320N]		
84DMS-18B	Bi-pl-carb-chl-ap	-	LEIC	Altered gabbroic pod adjacent to pegmatite; GR [ <u>5</u> 9545E <u>49</u> 6275N]		
84DMS-19	Opx coronite	WD: opx,cpx,sym,gt sp-pl,ilm,bi,ampi	-	Coronite with D1 replaced by Opx GR [59670E 496280N]		
850MS-4	opx-cpx-amp-gt- bi-amph-pl-op	ED: opx;gt;pl;ilm;b:	LEIC	Rextallised metagabbroic pod GR [58454E 496730N] (=84DMS-45A)		
84DMS-125C2	Caronite		LEIC	Adjacent to pegmatite		
84DMS-125C3	•	-	LEIC/CGS	Distant from pegmatite GR ( <u>5</u> 9520E <u>49</u> 620N]		
840MS-157A	Opx coronite	ED: cpx,plag,amph,gt	LEIC/CGS	Evolved (no al, sym), but relict coronite; GR [59705E <u>49</u> 6300N]		

# METAGABBROS (cont'd)

OPEONGO	MINERALOGY	PROBE	WHOLE ROCK	GRID REFERENCE/COMMENTS
84DMSA-2A	Opx-cpx-amph-gt-pl	ED: opx,gt,pl,ilm	-	Rextallised gt-bearing metagabbro
	prim cpx-op-bi-ap	bi, amph		GR (71070E 505090N)
84DMSA-X1	Coronite	-	LEIC/CGS	≡ 850MSA-8; GR ( <u>7</u> 0970E <u>50</u> 5230N)
85DMSA-8A	Biotite-rich	-	LEIC	Biotite segregation within gabbro
85DMSA-8B	Coronite	WD: ol;opx;cpx;sym; gt;sp-pl	LEIC/CGS	Symplectite-bearing coronite with no moat plagioclase; GR ( <u>7</u> 0950E <u>50</u> 5225N]
		ED: sp.mt, amph.pl		
B4DMSA-9A	Opx-cpx-prim cpx-	WD: opx,cpx,prim cp	× -	Evolved and rextallised metagabbro
	pl-amph-op-ap-biot	ED: amph,pl		with no gt; GR [ <u>7</u> 0875E <u>50</u> 525N]
84DMSA-11A	Opx-cpx-amph-gt-pl		LEIC	Contact amphibolite
	bi-op-ap-chl			GR [ <u>7</u> 0745E <u>50</u> 5195N]
85DMSA-11A	Coronite	WD: sp-pl	LEIC/CGS	(opx-gt) symplectite and primary biot
		ED: ol,opx,cpx,prim cpx,pl,gt		GR ( <u>7</u> 0755E <u>50</u> 5200N)
84DMSA-118	Prim cpx-opx-gt	• · · · · •	LEIC	Chilled, rextallised relict meta-
	amph-bi-op-ap-pl			gabbro; GR ( <u>7</u> 0745E <u>50</u> 5195N)
84DMSA-11C	#	-	LEIC	as above
84DMSA-110'	Coronite	-	LEIC/CGS	GR 170755E 505200N]
84DMSA-11E	Prim cpx-opx-cpx	-	LEIC	Foliated metagabbro
	amph-pl-ap-bi-op			GR 170765E 505200N3
84DMSA-11F	Coronite	WD: el.opx,cpx,gt		Fe-rich coronite metagabbro
		sp-pl,sym,ilm,mt,		GR ( <u>7</u> 0755E <u>50</u> 5200N]
		amph, bi		
		ED: sp.pl		
85DMSA-11G	Opx-cox-amph-gt	ED: opx,cpx,gt,pl	-	Foliated, porphyroclastic
	bi-prim cox-op-pl	amph.biot		metagabbro; GR [ <u>7</u> 0765E <u>50</u> 5200N]
84DMSA-13A	Opx-cpx-prim cpx-		LEIC	Rextallised, relict metagabbro with
	amph-pl-op-biot			no gt; GR ( <u>7</u> 0655E <u>50</u> 5185N)
84DMSA-138	Coronite	-	LEIC/CGS	GR (70680E 505180N)
84DMSA-13C	Opx-cox-prim cox-	-	LEIC	Foliated, clotty metagabbro from
	amph-gt-pl-bi-op-ar			shear zone; GR [ <u>7</u> 0670E <u>50</u> 5185N]
84DMSA-X2	Opx-cpx-amph-gt-bi-	•	-	LEICFoliated metagabbro
	op-ap-rare gt			# DMSA-13; GR [ <u>7</u> 0665E <u>50</u> 5180N]
85DMSA-138	Coronite	KWD: ol.opx.prim cpx	-	GR ( <u>7</u> 0680E <u>50</u> 5180N)
		gt.amph.sp.pl		
84DMSA-13M	Coronite	W0:01.0px.cpx.prim C	px -	Very coarse grained with cpx incl
		gt,sp-pl,ilm,bi,amph	•	in plag GR ( <u>7</u> 0680E <u>50</u> 5180N)
850454-120	Data and all and	EU: limimt	- 1	Partially restallised plag-rich
030113A~13F	Frim cpx-pi-opx-	the block and	iht -	laver: GR (70675E 505180N)
850454-162	chx-op-gt-amp-ot	11m,010t,ampri	1510	Rextalliged pod: GR [71980E 504180N]
850MSA-1649	Prin coversion	-	IFIC	Relict-textured metagabbro
	Dison-pi-seph-ec-se	-		GR [71570E 504110N]
85DMSA-165	P. op-or-ampu-sp-ap Coronita	KWR: al.ony.cny.ct	LEIC/CGS	Opx not always present in corona
		ilm.pl.amph		GR (70895E 505835N)
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# METAGABBROS (cont'd)

HUNTSVILLE	MINERALOGY	PROBE	WHOLE ROCK	GRID REFERENCE/COMMENTS
50MSH-5E	Prim cpx-opx-cpx- pl-amp-bi-gt-op	• = = + = + = = = = = = = = = = = = = =	LEIC	Relict, rextallised metagabbro GR [63210E 502280N]
85DMSH-5F	Coronitelevalved)	KWD: opx,cpx,gt,sp prim cpx,ilm,amph	LEIC/CGS	Opx-cpx core to coronae GR [63145E 502285N]
850MSH-15	Prim cpx-cpx,gt,pl amph,bi,op,chl	•	LEIC	Rextallised metagabbro GR [63725E 502330N]
850MSH-18D	Prim cpx-opx-cpx-g	t –	LEIC	Foliated, relict textured meta- gabbro: GR [63665E 502305N]
850MSH-18G	Relict coronite	ED: Prim cpx,opx,gt cpx,pl-amph-spin	-	Recrystallised, relict textures GR [63665E 502305N]
85DMSH-18H	Opx-cpx-gt-pl-op-am		LEIC/CGS	Rextallised: GR [62665E 502295N]
85DMSH-18I	Relict coronite	•F	LEIC/CGS	Rextalliged: GR [62665E 502290N]
85DMSH-55	Ol-opx-prim cpx- gt-pl-op-bi-amph	WD: el.gt.opx ED: amph.pl.ilm.cpx	-	Ol-rich metagabbro with rextallised plag; GR 163845E 502435N3
85DMSH-56	Relict coronite	-	LEIC	Rextallised; GR [63825E 502430N]
85DMSH-84C	Relict coronite	WD: cpx,prim cpx,gt ED: pl,sp,ilm,bi,am	- P	Relict, rextaliseed with Gt pseudo- morphing plag; GR [63370E 502215N]

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85DMSS-1A	Cpx-gt-pl-op-sp amph-ap	•	LEIC	Gt spotted rextallised meta- gabbro: GR [63270E <u>50</u> 0700N]
85DMSS-18	Opx-cpx-gt-pl-	WD: cpx,gt,amph	LEIC/CGS	Rextallised with gt pseudomorphs
	amph-op-prim cpx	ED: opx,cpx,pl,amph		of plag; GR ( <u>6</u> 3270E <u>50</u> 0700N]
85DMSS-1C	Opx-cpx-gt-pl-op-	WD: opx,cpx,gt,amph	LEIC	Vein-network metagabbro
	amph-biot	ED: plag,ilm		GR [ <u>6</u> 3270E <u>50</u> 0700N]
85DMSH-1B	Relict coronite		LEIC/CGS	Rextallised; GR [62540E 501620N]
85DMSH-4C	Coronite	ED: ol.opx.cpx.pl,	-	Plag starting to rextallise
		prim cpx, amph, bi		GR [62425E 502150N]
85DMSH-4F	Relict coronite	-	LEIC/CGS	Rextalliged; GR [62426E 50290N]
85DMSH-4G	Coronite	KWQ: ol.opx.cpx.gt.	LEIC/CGS	Olivine kernals remain
		mt,ilm,pl,bi,amph,sp		GR [ <u>6</u> 2390E <u>50</u> 2130N]
850MSH-101A	Prim cpx-gt-pl-op	-	LEIC	Gt spotted rextalllised meta-
	amph-biot			gabbro; GR [ <u>6</u> 2400E <u>50</u> 3110N]
85DMSH-1018	Relict coronite	-	LEIC/CGS	No elivine; GR [62415E 503110N]
85DMSH-101C	Coronite	WD: ol.opx.cox.pl.st	LEIC/CGS	GR 162415E 503115N1
		sym.prim cpx.bi.amoh		-
850MSH-1010	Relict coronite		LEIC/CGS	No olivine; GR [ <u>6</u> 2415E <u>50</u> 3110N]

# METAGABBROS (cont'd)

ROSSEAU	MINERALOGY	PROBE	WHOLE ROCK	GRID REFERENCE/COMMENTS
85DMSR-9	Gt-cpx-amp-p1-op-b		LEIC	Gt amphibolite; GR [ <u>6</u> 0945E <u>50</u> 1080N
85DMSR-11	Relict coronite	-	LEIC/CGS	Rextallised; GR [ <u>6</u> 0555E <u>50</u> 1175N]
850MSR-22	Relict coronite	ED: opx.cpx.pl.gt ilm,bi,amph	LEIC/CGS	Rextallised; GR [ <u>6</u> 1220E <u>50</u> 0465N]
85DMSR-28	Coronite	WD: ol.opx,cpx,sym, gt,prim cpx,sp-pl FD: olm.amph.biot	LEIC/CGS	GR ( <u>6</u> 0320E <u>50</u> 0520N)
850MSR-30	Coronite	WD: sym,sp-pl ED: ol,opx,cpx,gt,	LEIC/CGS	Discontinuous opx layer, cpx dominates; GR [ <u>6</u> 0355E <u>50</u> 0600N]
		prim cpx,pl,ilm,bi,	amp	
BSDMSR-31B	Relict coronite	-	LEIC	No alivine; GR [ <u>6</u> 0075E <u>50</u> 0430N]
B5DMSR-38	Gt-pyx-amp-op-pl	-	LEIC	Rextallised; GR [ <u>6</u> 1105E <u>49</u> 9630N]
B5DMSR-48A	Opx-gt-amp-pl-op-a	p –	LEIC	Gt-spotted amph; GR [61070E 499555
BSDMSR-50A	Amp-gt-pl-bi-op	· •	LEIC	Gt-spotted amph; GR [ <u>6</u> 0680E <u>49</u> 9745
B5DMSR-82	Coronite	WD: ol,opx,cpx,sym	LEIC/CGS	GR ( <u>6</u> 0650E <u>50</u> 0880N]
		gt,sp-plag,prim cpx ED: ilm,biot,amph		
KAWAGAMA		<u></u>		
35DMSD-3	Biot-rich		LEIC	Rextallised; GR [67330E 501320N]
95DMSD-4A	-	-	LEIC	Gt amphibolite: GR [67375E 501375N]
350MSD-9	Opx-cpx-gt-pl-	WD: opx,cpx,gt,amph	-	Vein-network metagabbro with qtz
	amph-bi-op-gtz	ED: pl,bi,amph,opx,c	:px	GR [ <u>6</u> 7015E <u>50</u> 1250N]
SDMSD-32B	-	-	LEIC	Mf amphibolite; GR [67310E 501425N]
SDMSD-38B	-	-	LEIC	Relict, rextallised; GRI <u>6</u> 7485E
01690N1				
SDMSD-48A	-	-	LEIC	• • GR ( <u>6</u> 6950E <u>50</u> 1365N
350MSD-62C	Opx-cpx-gt-pl-	WD: opx,cpx,gt ED: ol.amob	LEIC/CGS	McLintock subdomain, rextallised metagabbro: GR [65750E <u>50</u> 1900N]
BSDMSD-68	Coronite	KWD: ol.opx.cpx.st	LEIC/CGS	D1-most-gt with very little opx
		nl.en.ilm.hi.amph	• •	GR [67180E 501400N]
15DMSD-91	Opx-cpx-gt-pl-ap-op		LEIC	Gt-spotted; GR [ <u>6</u> 6550E <u>50</u> 0850N]
IOSK				
35DMSK-2	Coronite	KWD: ol.opx.cpx.sym at.sp-pl.ilm.bi.amp.	LEIC	Some pale amph in ol-coronae GR [ <u>6</u> 1960E <u>50</u> 4240N]
5DMSK-5	Relict coronite	erek katasutaatamkt	LEIC	Part rextallised; GRIS2030E 504150N
SDMSK-10	Coronite	WD: ol.opx,cpx,gt,	LEIC/CGS	Sp-bearing symplectite common
		gt-sym,sp-sym,sp-pl		GR 151/30E 504390NJ
5DMSK-13	Relict coronite	-	LEIC/CGS	No olivine; UH ( <u>b</u> 1950) <u>DU</u> 4240NJ
SDM-230	Coronite	WD: al;epx;cpx;sym gt;prim cpx;sp-pl	-	Northeastern Kiosk Domain snows strain-induced annealing of spinel
AITT	·····			
 50MS8-10	Relict coronite E	D: cox.amo.pl.gt.ilm	LEIC/CGS	Rextallised; GR ( <u>5</u> 5670E <u>50</u> 4310N)

# 2) HOST GNEISSES

GO HOME	MINERALOGY		PROBE	WHOLE ROCK	GRID REFERENCE/COMMENTS
84DMS-68	Qtz-pl-sill-gt-	WD:	gt,biot		Sill-bearing paragneiss
	bi-op	ED:	gt,bi,sill,plag		GR ( <u>5</u> 9690E <u>49</u> 6185N]
84DMS-17C	Fapr-qtz-amp-bi-ap-		-	LEIC	QF gneiss; GR [ <u>5</u> 9175E <u>49</u> 6195N]
	op-sph-rut-darb-mus	c		-	
84DMS-51B	Gt-cpx-pl-amph-	WD:	gt,cpx,amph	-	Mafic boudin adjacent to anorthosite
	bi-op-ap	E0:	gt,cpx,amp,pl,op		GR ( <u>5</u> 9670E <u>49</u> 6185N]
84DMS-51F	Cpx-amp-bi-pl-op-ap	ED:	cpx,bi,amp,pl,kf	sp -	Blastomylonite; GR [59660E 496190N]
840MS-918	Qtz-kfsp-pl-cpx-gt-	ED:	cpx-gt-pl-kf <b>s</b> p	-	Marble association;
	cc-sph				GR [59445E 496795N]
84DMS-91E	Pl-kfsp-amph-cpx-		-	LEIC	Syenitic layer associated with Mbl
	qtz-sph				GR [ <u>5</u> 9445E <u>49</u> 6795N]
84DMS-99A	Cpx-pl-qtz-ves-op	ED:	cpx-pl-ves	-	Mb1 inclusion; GR [ <u>5</u> 9435E <u>49</u> 6745N]
840MS-103A	Qtz-fsp-bi-amph-		-	LEIC	Gt-bearing Green Isalnd orthogneiss
	gt-ap-sph-op				GR [ <u>5</u> 9745E <u>49</u> 5975N]
84DMS-105	Gt-amp-bi-pl-gtz-		-	LEIC	Melanocratic gt-bearing gneiss
	op-ap				GR ( <u>5</u> 9770E <u>49</u> 6005N]
84DMS-111B	4 H	ED:	gt,amph,bi,pl	-	As above; GR [ <u>5</u> 9890E <u>49</u> 5970]
84DMS-115	-		-	LEIC	Gt-orthogneiss; GR [59985E 495865N]
84DMS-124	Gt-bi-qtz-pl-amph	WD:	gt,biot	-	Gt-bi gneiss; GR [ <u>5</u> 9675E <u>49</u> 6035N]
		E0:	gt,bi,amph,pl		
84DMS-172A	Cpx-cc-pl-qtz-fsp-	E0:	cpx,pl,scap,woll	-	Marble; GR [ <u>5</u> 9900E <u>49</u> 6995N]
	aph-op-woll-scap				
84DMS-1728	Amp-gt-bi-pl-op-qtz	ED:	amph,gt,pl,bi.op	-	Amphibolite; GR [ <u>5</u> 9900£ <u>49</u> 6995N]
84DMS-173	Gt-bi-kfsp-pl-ap-op	ED:	gt,bi,kfsp,pl	-	Gt-orthogneiss; GR [599965E 496580N]
850MS-2A	Opx-cpx-gt-amph-pl-	W0 :	opx,cpx,gt	-	Two pyroxene-gt granulite
	qtz-bi-op	ED:	pl,ilm,bi,amph		GR ( <u>5</u> 9825E <u>49</u> 8315N]

OPEONGO

cm

: opx;cpx	-	Mf granulite layer in granitoid GR [ <u>7</u> 1065E <u>50</u> 5055N]
gt;cpx plag	-	Leucocratic granulite GR [ <u>7</u> 1030E <u>50</u> 5190N]
-	LEIC	Gt-granulite; GR [ <u>7</u> 0430E <u>50</u> 5110N]
gt,cpx,pl,scap	-	Calc-silicate pod in granulite GR [ <u>7</u> 0430E <u>50</u> 5110N]
opx,cpx,gt	-	Mf gt-granulite with qtz GR [ <u>7</u> 0930E <u>50</u> 5070N]
-	LEIC	Mf granulite; GR [71195E 504920N]
gt,cpx plag,amph	-	Mf gt-granulite (no qtz) GR [ <u>7</u> 1240E <u>50</u> 4885N]
gt,pl,kfap	-	Sill-bearing paragneiss
cpx,kfsp,wo,scap		Marble from Lake of Two Rivers
Bi,pl,kfsp,gt, .,mt	-	Gt-granulite from southern Opeongo GR [ <u>7</u> 1920E <u>50</u> 3800N]
1 ×	: Bi,pl,kføp,gt, x,mt	: Bi,pl,kfsp,gt, - x,mt

# HOST GNEISSES (cont'd)

HUNTSVILLE	MINERALOGY	PROBE	WHOLE ROCK	GRID REFERENCE/COMMENTS
85DMSH-7B	Ol-opx-cpx-sp-op-amp	ED: 01.00x.00x.80	amp -	Ultramafic: GR [62625E 502375N]
85DMSH-79	Cpx-amp-bi-pl-ol-op	-	LEIC	Mf-UM associated with metabasic and
				anorthosite; GR [ <u>6</u> 3005E <u>50</u> 2960N]
850MSH-100	Gt-opx-cpx-qtz-pl-	WD: opx,cpx,gt	-	Two pyroxene-gt granulite
	amph-bi-op	ED: amph, pl, ilm		GR (62965E 502450N)
850MSH-1028	0px-cpx-gt-amph-pl-o	- q	LEIC	Gabbroic phase associated with
				UM peridotoite; GR [63590E 502160N]
850MSH-1020	01-opx-cpx-amp-phlog	KWD: al,apx.cpx.gt	L -	Ol-gt pyroxenite/peridotite
	gt-sp-op-(opx-sp)sym	sp,phlog,amp		GA [ <u>6</u> 3590E <u>50</u> 2160N]
850MSH-107A	Opx-cpx-pl-amp-bi-	ED: opx,cpx,amph	LEIC	Pyroxenite associated with meta-
	op-ap	bi,pl		gabbro; GR [ <u>6</u> 5225E <u>50</u> 1804N]
85DMSH-107C	Opx-cpx-gt-amp-bi-	WD: gt,cpx,opx	LEIC	Metagabbro (not coronitic affinity)
	pl-op-ap	ED: pl,il,biot		GR [ <u>6</u> 5225E <u>50</u> 1804N]
850MSH-108A	Opx-cpx-gt-amph-bi-	WO: cpx,opx,gt	LEIC	Banded two pyx-gt granulite
	pl-op-ap	ED: pl,amph,bi,op		GR ( <u>6</u> 3905E <u>50</u> 2240N]
850MSH-110A	Qtz-pl-kfsp-gt-bi-	WD: cpx,gt,biot	-	Gt-cpx paragnelss;
	cpx-amp-op-ap-sph	ED: pl,amph.cpx		GR [ <u>6</u> 2845E <u>50</u> 3070N]
850MSH-111A	Gt-bi-sill-op-qtz-pl	WD: gt,biot	-	Sill-bearing paragneiss
		ED: bi,pl,gt		GR [ <u>6</u> 3680E <u>50</u> 1990N]
ROSSEAU				<u></u>
850MSR-6	Gt-cox-ol-amo-rut-oo	WO: at.cox	*****	Meta-eclogite associated with
		ED: amp.pl		anorthosite; GR [61410E 501450N]
850MSR-27	Gt-cox-opx-amp-ol	WD: cox.gt	-	Gt-cpx-rare opx granulite
	Kfsp-gtz-op	ED: pl.amph		GR [60510E 500030N]
850MSR-15	Ol-gt-cpx-sp-amph-	ED: 01.0px,cpx,bi,	LEIC	Relict gt-peridotite
	phlog-op-(opx-sp)sym	amph, Cr-sp, gt		GR [61160E 500610N]
85DMSR-39A	Ol-oxp-cpx-op-sp-bi	•	LEIC	Ultramfic; GR [ <u>6</u> 1570E <u>49</u> 9935N]
85DMSR-398	-	-	LEIC	Ultramafic: GR [ <u>6</u> 1570E <u>49</u> 9935N]
84DMSR-44C	Cpx-pl-amph-bi-op-qt:		LEIC	Rextallised metagabbro from margin
				of DGN; GR [ <u>6</u> 1105E <u>49</u> 9630N]
85DMSR-78A	Cpx-opx-gt-amph-pl-	-	LEIC	Gt-spotted metagabbro adjacent to
	bi-opx-op-ap			anorthosite; GR [ <u>6</u> 0740E <u>50</u> 0390N]
PARRY SOUND				
850MSP-2	Prim cpx-pl-amp-opx	ED: opx,amph.gt.ol	LEIC/CGS	Rextallised, relict metagabbro
	Cpx-gt-op			(not coronite); GR [ <u>5</u> 8870E <u>50</u> 5500N]
85DMSP-5A	Gt-opx-bi-amp-pl-	WD: gt,opx,biot		
	qtz-op	ED: pl,bi,amp,ilm,m	nt -	Granulite cut by pyx-bearing neo-
		• • • • •		some: GR [ <u>5</u> 8400E <u>50</u> 4175N]
850MSP-7	Gt-bi-sill-gtz-pl	WD: gt,biot	-	Sill-bearing paragneiss
	• •	ED: plag		GR [ <u>5</u> 7980E <u>50</u> 3600N]
850MSP-13A	GT-bi-pl-qtz-ky-	WD: gt,biot	-	Ky-bearing paragneiss
	musc-op	-		GR ( <u>5</u> 7375E <u>50</u> 2560N)
850MSP-16	Opx-cpx-pl-amp-op-	ED: opx,cpx,gt,p1,	-	Banded two pyroxene granulite
	Kfsp	amph, kfsp		GR ( <u>5</u> 8790E <u>50</u> 5350N]

# HOST GNEISSES (cont'd)

KAWAGAMA ZO	NE MINERALOGY	PROBE	WHOLE ROCK	GRID REFERENCE/COMMENTS		
85DMSD-10B	Ol-opx-cpx-amph-gt phlog-sp-op-pl	ED: 01,0px,cpx,gt amp,phlog,pl,sp,cr		Relict gt peridotite/pyroxenite GR [ <u>6</u> 6975E <u>50</u> 1270N]		
850450-TUC		-	LEIC/CGS	• •		
850MSD-76	Opx-gt-bi-pl-kf <b>s</b> p- qtz-op	WD: opx,gt,biot ED: plag	-	Gt-bi granulite; GR [ <u>6</u> 6625E <u>50</u> 1385N]		
850MSD-80	Opx-cpx-pl-qtz-amp- op-bist		LEIC	Metagabbro (not coronitic affinity) GR [66690E 501745N]		
85DMSD-130	• •	-	LEIC	Mf amphibolite: GR [66640E 500800N]		
850MSD-138A	Opx-gt-qtz-bi-pl- op-ap	WD: opx,biot,gt ED: plag,ilm	-	McLintock subdomain (north of Kawa- gama zone); GR [66480E 501695N]		

# 3) ANORTHOSITIC & ASSOCIATED GNEISSES

GO HOME	MINERALOGY	PROBE	WHOLE ROCK	GRID REFERENCE/COMMENTS
84DMS-27C	Gt-pl-amph-op-biot	ED: gt,amp,bi,pl	*****	Mf assoc; GR ( <u>5</u> 9965E <u>49</u> 6450N)
84DMS-35C	Amph-pl-biot-op	ED: amph.pl.biot	-	Leucogabbro; GR (60080E 496380N)
84DMS-38	-	-	LEIC	Mf assoc; GR (59735E 496555N)
84DMS-57C	-	-	LEIC	Mafic lense; GR [ <u>5</u> 9715E <u>49</u> 6140N]
84DMS-57D	Gt-pl-amph-bi-op-ap	ED: amp,gt,pl,bi	-	Leucogabbro; GR [ <u>5</u> 9715E <u>49</u> 6140N]
84DMS-66	Amp-pl-bi-op-ap-sph	-	LEIC	Mf assoc; GR [ <u>5</u> 9825E <u>49</u> 6095N]
84DMS-83B	Amp-pl-op-ap	-	LEIC	Leucogabbro; GR [ <u>6</u> 0005E <u>49</u> 4955N]
840MS-134A	Opx-amp-gt-bi-act-	ED: gt,amp,mica,pl	-	Coronite leucogabbre GR [5964DE 496570N]
840MS-1348	• •	-	LEIC	
84DMS-134C	Amp-st-sl-bi-os+as	FD: amp.pl.gt.op.#	ica -	Foliated anor: GR [59640E 496570N]
84DMS-182	Cox-amo-nl-enid-	ED: cox.amp.pl.epi	d -	Anorthosite: GR [59425E 496634N]
	30-00-2P			
85DMS-3		-	LEIC	Anorthosite; GR [ <u>6</u> 0050E <u>49</u> 3690N]
85DMS-5	-	-	LEIC	Anorthosite; GR [59660E 496580N]
85DMS-9A	•	-	LEIC	Anorthoeite: GR [ <u>6</u> 0205E <u>49</u> 6270N]
85DMSH-9B	Cpx-amp-gt-bi-pl-op	-	LEIC	Leucogabbro; GR [ <u>6</u> 2780E <u>50</u> 2770N]
85DMSH-99	Cpx-opx-amp-bi-pl-gt	-	LEIC	Leucogabbro; GR [ <u>6</u> 3085E <u>50</u> 2210N]
	scap-sph-ap			
85DMSN-2A	-	-	LEIC	Anorthosite from margin of Novar subdomain: GR [62290E 503950N]
85DMSR-12A	-	-	LEIC	Mf pod; GR (60920E 500625N)
85DMSR-12C	-	-	LEIC/CGS	Anorthosite: GR [60929E 500625N]
85DMSR-13	Amp-ot-nl-scap-zr	-	LEIC	Anorthosite; GR [61110E 500650N]
850MSR-16A	Cpx-amp-gt-op-	ED: cpx,amp.pl.ilm	LEIC/CGS	Leucogabbro with relict prim cpx
	pl-epid	epid.gt		GR 1 <u>6</u> 1195E <u>50</u> 0605N)
85DMSR-45	Amp-pl-mica	-	LEIC	Anorthosite; GR [ <u>6</u> 0925E <u>49</u> 9735N]
B5DMSM-4	-	-	LEIC	Anorthosite; GR [ <u>6</u> 0500E <u>49</u> 8550N]
85DMSP-3B	Opx-cpx-gt-amp-bi-sca		LEIC	Mf assoc: GR [ <u>5</u> 8600E <u>50</u> 5540N]
85DMSP-3C	Cpx-gt-pl-amp-bi-	WD: cpx,gt	-	Leucogabbro; GR [ <u>5</u> 8600E <u>50</u> 5540N]
	scap-chl-op	ED: pl,amp,mt		
850MSP-3G	-	-	-	Leucogabbre; GR [ <u>5</u> 8600E <u>50</u> 5540N]

# 4) SAPPHIRINE-BEARING SAMPLES

ASSOCIATION	I MINERALOGY	PROBE	GRID REFERENCE/COMMENTS
85DMSR-3	Sapp-sp-gt-cpx-opx amp-pl-phlog-alsil-co	KWD: all	Sapphirine-bearing anorthositic assoc = 81DMA-389A; GR [ <u>6</u> 0720E <u>50</u> 0345N]
850MSR-13A	Cor-sp-gt-pl-amp-bi- mica-op	EO: gt,bí,amp,musc sp.pl	Sp-bearing knots in mf anorthositic association: GR [61115E 500650N]
850M-203	Gt-pl-sapp-cor-rut- ky-amp-phlog	KWD: sapp,ky,gt,amp, biot	Sapp-knots, similar to DMSR-3 collected from boulder
ASSOCIATION	11	<u> </u>	
810MN-155E	Cpx-gt-ky-pl-sp-qtz amph-rut-musc-bi-op	KWD: gt,ky,cpx,qtz, pl.sp.musc.amph	Meta-ecolgite (no sapphirine left, replace by cor-sp-musc knots)
810MN-155F	Cpx-gt-ky-sapp-cor- pl-opx-amph-rut-op	KWD: gt,cpx,ky,pl, sapp,cor,amp	Sapphitn-bearing meta-eclogite
810MN-155G	Gt-opx-sapp-amp-qtz- ky-pl-cor-sp-musc-rut	KWD: gt,ky,rut,pl,opx sapp.cor.sp.musc.amp	Qtz-bearing meta-eclogite
850M-202	Gt-cpx-ky-sapp-sp- pl-rut-cor-zois-amp- op-phlog	KWD: gt,cpx,sapp,pl, rut,ky,cor,zois,amp,sp, phlog	Zoisite-bearing meta-eclogite (collected from boulder)

#### **APPENDIX II - whole rock geochemistry**

Fresh and unweathered samples for whole rock analyses were collected, where possible. from blasted road-cuts or power line excavations and away from site of pegmatite injection where metasomatic effects are likely. The samples were trimmed in the field to remove any weathered or contaminated surfaces and then crushed to a fine powder in the rock preparation laboratories of the Canadian Geological Survey. At Leicester, the powders were fused into glass discs for major elements and pressed into powder pellets for trace element analysis. Details of sample preparation are given in Marsh (1981-85). The analyses were carried out on a Philips PW1400 automatic sequential x-ray spectrometer (XRF) with 72-position changer. A Rhodium tube was used for both major elements and Nb, Zr, Y, Sr, Rb, Th, Ga, Zn and Ni trace elements, while a tungsten tube was employed for Cr, V, Ba, La. Ce and Nd. In-house and international standards were run with the samples and the mean and standard deviation for several mafic standards are given below in Table AII.1. The standard deviations only take into account machine reproduceability and as such the 7 errors can only be considered as minimum estimates of precision for XRF analyses as they and do not take into account human error. These results have been used as a covariance matrix in Chapter 6 for weighting least squares solutions.

TABLE AII.1: Mean & STD deviation for XRF data from selected standards.

MAJOR ELEMENTS:

	808-1	Std D	X	MRG-1(8)	Std D	X	MRG-1(A)	Std D	X
Si02	50.36	0.270	0.54	39.38	0.205	0,52	38.40	0.206	0.53
T102	1.28	0.014	1.11	3.75	0.010	0.26	3.72	0.017	0.45
A1203	16.57	0.069	0.42	8.53	0.100	1,17	8.41	0.081	0.97
Fe203	8.62	0.038	0.45	17.802	0.100	0.56	17.75	0.094	0.53
Mnû	0.14	0.003	2.24	0.17	0.0	0.0	0.17	0.0	0.0
MgC	7.59	0.055	0.73	13.805	0.169	1.22	13.34	0.140	1.04
CaO	11.24	0.047	0.42	15.03	0.037	0.25	14.92	0.033	0.22
Na20	3.08	0.283	9.21	0.72	0.028	3.81	0.66	0.09	13.46
K20	0.36	0.015	4.02	0.18	0.002	1.18	0.18	0.003	1.86
P205	0.173	0.018	10.29	0.067	0.003	4.95	0.072	0.003	4.73

THACE	ELEMENTS;	
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	808-1(ppm)	Z	MRG-1(ppm)	) %
Cr	305	1.20	519	1.42
V	235	1.37	568	1.16
8a	42	3.28	48	3.00
La	6	13.12	14	10.94
Ce	14	10.15	26	6.42
Nd	10	9.12	17	6.13
Nb	5	8.08	21	4.59
Zr	103	0.66	107	4.59
Y	27	2.56	14	4.79
Sr	195	0.63	275	0.68
RЬ	7	7.26	6	9.05
Th	1	59.18	3	51.30
Ga	16	4.97	20	4.33
Zn	72	2.95	208	2.47
ił	110	1.04	199	1.10

In addition several samples were also analysed by induced coupled plasma source spectrometry (ICP) in the laboratories of the Canadian Geological Survey. Here FeO was determined by rapid wet chemistry and the resulting  $Fe^3/Fe^2$  ratios are plotted against total iron (as  $Fe_2O_3$ ) in Figure. A11.1. The majority of samples lie between 0.2 and 0.3  $Fe^3/Fe^2$  and the mean of 0.25 has been adopted for norm calculations on Leicester analyses where there is no ferrous iron data available. For anorthosites and host gneisses a rather arbitrary value of 0.15  $Fe^3/Fe^2$  has been adopted for norm calculations, but was based on only a few FeO determinations in the CGS laboratories.

FIGURE AII.1: Fe3/Fe2 vs Total Iron.



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# <u>TABLE AII.2</u>: XRF results from coronite metagabbros, anorthosites, mafic and ultramafic gneiss

METAGABBRO SAMPLES FROM 1984 & 1985

Name	840MS13A	DMS125C2	DMS125	C3 DMS1578	85DMS4	85DMS6	85DMS7	85DMS8	84DMS188
e	10.00	(7.07	17 40	10 70		17 19	45 29	46.38	44.04
3102	40.02	41.21	41.15	40.(3	3 00	1 59	1 57	1.67	3.81
1102	1.92	2.04	2.50	3.13	2.33	10 72	17 18	18.22	17.66
ALZUJ	18.90	20.22	19.27	13.23	10.10	2 20	2 10	3 00	2.72
Fe2U3	2.32	1,96	2.00	2.41	3.01	2.30	9.10	8 50	10.90
FeU	9.26	7.85	8.70	9.88	12.02	0.40	0.16	0.50	0.04
Minu	0.15	0.13	U.14	U.16	0.19	7 63	10 13	8 77	9.03
ngu	7.53	5.58	6.33	4.49	6.03	0.20	7 79	8.23	3.87
CaU	7.81	8.48	9.11	8.72	8.05	0.33	2 62	2 92	2.82
Na20	3.80	3.76	3.57	3.67	3.66	3.10	2.03	0 64	3 20
K20	0.80	0.90	0.75	0.99	0.61	0.63	0.43	0.07	0.62
P205	0.51	0.46	0.42	0.63	0.45	U.24	0.13	00 22	99 71
Total	99.62	98.65	99.90	100.12	98.70	98.32	98.29	30.32	20.11
CIPW	Norms								
Cor									4.01
Or	4.73	5.33	4.41	5.87	3.60	3.72	2.90	3.78	18.91
АЬ	28.04	29.82	28.18	29.78	27.60	26.23	22.26	24.79	22.75
An	32.16	35.64	34.36	33.13	27.35	35.31	33.63	34.68	15.15
Ne	2.23	1.08	1.10	0.69	1.83				0.61
01	2.66	2.80	6.60	4.98	8.02	3.86	3.06	3.57	
Hy						6.34	6.59	6.74	
01	21.63	16.20	16.44	14.69	19.22	15.96	22.02	16.63	24.67
Mt	3.36	2.84	3.09	3,58	4.36	3.33	4.49	4.35	3,95
Ilm	3.65	3.87	4.75	5.94	5.68	3.02	2.91	3.17	7.24
Ap	1.18	1.07	0.97	1.46	1.04	0.56	0.44	0.63	1.44
_									
Irace	elements	in ppm.		20 E	17 6	84 5	59.8	115.9	161.1
Lr	21.9	53.8	66.U	20.3	106 1	111.6	110.1	114.2	302.8
v	103.1	113.2	150.4	183.4	130.1	248.3	229.0	242.9	430.0
ва	297.7	367.8	308.2	388.4	- C Q	7 6	4.3	6.6	22.4
La	15.3	14.0	15.2	20.4	0.3	20.5	18.9	20.8	46.6
Ce.	31.6	26.3	22.5	34.8	40.7	14.2	11.9	13.1	23.7
Nd	19.5	14.9	14.4	21.9	13.1	7 2	4.7	6.5	11.9
Nb -	8.5	8.2	8.7	11.8	<b>4.</b> 4	70 0	0.03	83.4	149.4
Zr	124.1	113.6	104.6	167.9	132.3	10.3	13.1	17.4	30.4
T	23.5	21.7	20.6	23.2	53.4	576 7	510.2	505.2	430.4
Sr	627.4	672.5	624.4	613.2	334.3	JJ0.1 0 7	6.4	8.4	78.3
HD T	11.3	14.6	13.5	12.1	9.2 2 7	5.1	4.2	3.5	0.5
íh n	1.7	1.6	0.9	1.9	3./ 22.0	3.1 21 Q	19.1	20.8	21.7
52	20.3	21.7	20.8	24.0	440 7	21.3 Qn 7	98.1	97.0	70.5
Zn	96.7	84.5	83.9	30.8	110.1	30.1 1/0 0	195 3	147.3	105.8
NI	145.7	99.3	110.0	50.4	27.0	143.0			

Name	84DMS518	84A-8X1	84A-110	84A11A	84A118'	84A11C'	84A110	84A11E'	844138
Si02	44.05	44.34	44.81	45.54	45.42	45.71	44.35	44.00	44.86
T102	2.21	5.42	4.52	3.90	3.29	3.37	5.15	5.74	5.26
A1203	16.32	16.65	15.04	16.76	16.77	16.74	15.29	12.29	13.79
Fe203	2.92	2.60	3.33	2.98	3.70	3.79	3,50	3.56	3.80
Fe0	12.60	12.60	13.30	11.91	10.80	10.90	12.80	14.22	11.10
MnO	0.22	0.19	0.23	0.21	0.19	0.20	0.21	0.24	0.20
MgO	6.71	5.38	4.95	4.69	6.38	8.23	4.77	4.49	4.97
CaO	12.01	7.92	7.65	7.98	7.83	7.90	7.62	8.15	8.88
Na20	1.44	3.48	3.47	3.98	3.89	3.21	3.61	3.41	3.65
K20	0.49	0.90	1.37	1.27	1.04	1.02	1.25	1.53	1.12
P205	0.37	0.44	0.72	0.78	0.66	0.69	0.63	0.82	0.56
Total	98.50	99.92	99.39	100.00	99.95	99.64	99.18	98.44	98.18
CIPW	Norma								0.50
Or	2.90	5.31	8.10	7.53	6.18	6.04	7.36	9.04	6.59
AЬ	12.19	27.95	27.78	27.55	26.37	27.16	27.86	26.46	26.78
An	36.63	27.17	21.42	24.11	25.22	28.26	21.84	13.72	17.96
Ne		1.07	0.86	3.32	3.04		1,29	1.30	1.00
Di	16.96	7.61	9.84	8.63	7.46	5.32	a <b>.</b> 83	17.81	18.31
Hy	10.22		~-			5.92		40.17	0 09
01	10.30	16.19	16.32	15.33	17.55	13.71	14.39	12-11 E 15	5.51
Mt	4.26	3.77	4.82	4.32	5.32	2.33	5.01	3.13	9.99
Ilm	4.20	10.29	8.58	7.41	6.25	6.4U	3.18	10.30	1 30
Αp	0.86	1.02	1.67	1.81	1.53	1.60	1,40	1.30	1.50
Trace	elements	in ppm.							
Cr	244.9	70.7	52.7	30.7	27.3	26.8	42.7	0.1	64.3
v	378.6	373.5	285.0	251.6	223.9	219.3	344.8	468.9	447.5
Ba	146.6	340.2	484.6	489.1	384.6	388.6	458.8	545.3	427.1
La	16.0	20.1	22.6	22.6	21.2	21.5	25.2	31.0	23.7
Ce	47.7	32.2	56.4	44.8	40.3	37.9	47.0	55.7	41.U
Nd	37.4	17.7	35.7	28.7	23.7	26.3	27.8	34.9	24.1
Nb	11.3	12.0	17.1	14.6	12.3	12.5	16.6	17.3	12.5
Zr	168.9	124.9	244.5	197.6	172.2	176.0	188.6	249.7	182.6
Y	60.8	24.9	46.6	40.6	33.1	33.0	35.7	53.7	40.0
Sr	214.7	488.2	427.3	510.7	519.7	518.4	431.8	327.9	367.0
RЬ	11.6	10.9	19.9	19.6	13.5	13.5	17.3	26.7	18.0
Th	5.0	3.2	5.5	3.2	1.9	2.2	0.7	0.9	1.4
Ga	28.1	23.9	27.8	26.4	24.1	23.8	25.2	27.8	24.4
Zn	125.9	117.0	148.5	132.6	119.1	120.5	132.0	123.3	110.1
N1	55.5	55.4	41.5	46.8	89.3	89.5	37.6	23.3	J

.

Name	84A13C <sup>*</sup>	84A-X2	85A-8B	85 <b>A-9A</b>	85A-11A	854-163	85A-164	85A-165	84A13A <sup>*</sup>
Si02	45.43	44.55	43.30	45.87	44.78	46.21	44.34	45.45	42.47
Ti02	4.53	3.91	5.29	3.35	4.56	4.14	4.52	3.56	5.63
A1203	15.06	15.30	15.44	17.10	15.08	14.76	14.84	16.40	12.63
Fe203	3.08	3.04	4.20	2.92	4.10	3.12	3.27	4.40	3.48
Fe0	12.32	12.17	12.40	11.69	11.80	12.49	13.07	10.70	13.93
MnO	0.21	0.21	0.21	0.19	0.22	0.20	0.22	0.20	0.22
MgO	4.41	5.49	5.83	6.41	4.21	4.92	4.87	5.51	7.06
CaO	7.71	8.14	7.50	7.80	7.04	7.96	7.93	8.03	9.21
Na20	4.02	3.75	3.18	3.19	4.11	3.87	3.59	3.58	2.87
K20	1.30	1.12	0.95	1.02	1.63	1.38	1.23	1.06	0.76
P205	0.76	0.69	0.42	0.46	0.92	0.69	0.62	0.55	0.41
Total	98.84	98.38	98.72	100.00	98.45	99.74	98.50	99.44	98.68
CIPW	Norms								. =.
Or	7.71	6.64	5.61	6.03	9.63	8.16	7.27	6.26	4.51
Ab	29.55	25.74	26.80	26.99	28.52	28.87	26.45	27.59	20.85
An	19.21	21.60	25.06	29.34	17.89	18.84	20.75	25.56	19.33
Ne	2.42	3.25			2.77	2.10	2.13	0.51	1.85
Di	11.72	11.81	7.71	5.23	9.14	13.42	12.09	8.76	19.44
Ну			1.70	2.79					
01	13.42	15.90	14.63	17.96	12.62	14.38	15.05	14.58	16.00
Mt	4.47	4.41	6.09	4.24	5.94	4.53	4.74	6.38	5.05
Ilm	8.60	7.43	10.05	6.36	8.66	7.86	8,58	6.76	10.69
Åр	1.76	1.60	0.97	1.07	2.13	1.60	1.44	1.27	0.92
Trace	elements	in ppm.							401 8
Cr	101.9	81.5	60.8	122.4	63.3	50.0	35.9	101.9	104.4
V	299.2	262.1	347.1	244.4	245.8	266.1	318.6	244.8	323.0
Ba	539.1	327.4	359.2	445.1	568.8	513.1	538.4	442.0	40.2
La	29.8	26.8	12.8	12.4	23.6	20.4	19.4	11.1	15.2
Ce	55.8	48.8	31.7	33.0	60.9	47.3	44.5	42.9	10 4
Nd	33.0	27.6	20.9	22.7	39.8	32.8	29.4	23.1	10.4
NЬ	16.3	15.4	11.5	10.7	19.5	12.6	14.1	11.1	10.3
Zr	219.2	196.6	149.0	150.1	284.4	173.9	196.8	101.3	25 8
Y	44.3	43.4	29.9	30.6	49.6	41.9	42.8	J7.J 575 0	261 d
Sr	474.7	430.6	474.6	540.7	429.0	415.3	433.8	43.0	7 2
RЬ	21.1	19.5	11.1	14.7	26.6	25.8	15.4	13.8	0.1
Th	1.3	0.6	4.6	4.9	5.8	6.4	4.5	4.9 97 0	20.6
Ga	25.1	25.9	27.7	26.5	28.3	26.9	26.2	122 1	128 6
Zn	132.6	120.9	126.0	119.9	141.1	144.6	134.3	59.9	74.3
Ni	32.3	59.6	53.9	82.4	38.9	41.5	72.1	50.0	1719

Name	DMSB1	85A-8A	DMSH5E	DMSH5F	DMSH15	DMSH18H	DMSH18D	DMSH18I	DMSH56
Si02	46.50	43.81	45.29	44.57	46.95	42.87	47.09	46.24	46.64
T102	4.36	2.52	2.10	1.45	2.21	3.23	1.83	2.42	2.51
A1203	15.01	12.80	16.22	17.62	17.92	15.87	16.55	15.65	14.64
Fe203	2.94	1.84	2.66	2.52	2.47	5.00	2.42	2.51	2.76
FeD	11.78	7.35	10.65	10.09	9.88	12.50	9.67	10.05	11.02
Mnū	0.20	0.15	0.20	0.18	0.18	0.24	0.18	0.20	0.22
MaO	4.99	8.86	7.85	8.50	6.52	6.22	7.21	6.87	6.34
CaO	8.67	7.55	9.67	9.74	10.41	77.7	10.25	10.85	10.57
Na20	3.88	1.30	2.64	2.47	2.93	3.13	2.68	2.82	3.06
K20	1.20	7.10	0.52	0.36	0.64	0.60	0.46	0.47	0.62
P205	0.49	2.84	0.22	0.13	0.25	0.47	0.19	0.34	0.27
Total	100.02	96.11	98.02	97.63	100.35	97.90	98.53	98.42	98.65
CIPW	Norma								
Or	7.09	35.79	3.07	2.13	3.78	3.55	2.72	2.78	3.66
Ab	27.91		22.34	20.80	24.42	24.79	22.68	23.86	24.70
An	20.00	8.13	30.88	35.94	33.86	27.49	31.78	28.66	24.39
Lu		4.83							
Ne	2.67	5.96		0.05	0.20				0.65
Di	16.39	8.65	12.82	9.42	13.25	6.58	14.60	18.80	21.67
Hv			1.62			0.36	7.01	0.74	
01	12.29	18.72	18.93	22.58	16.48	18.96	12.32	14.56	14.19
Mt	4.27	2.66	3.86	3.66	3.58	7.25	3.50	3.64	4.00
Ilm	8.28	4.79	3.99	2.75	4.20	6.13	3.48	4.60	4.77
Ap	1.14	6.58	0.51	0.30	0.58	1.09	0.44	0.79	0.63
Trace	elements	a in ppm.							
Cr	90.9	329.3	61.1	40.7	65.2	48.7	146.7	201.3	105.5
v	359.7	193.2	290.7	169.4	278.8	261.7	321.3	365.7	401.7
Ba	405.2	10184.0	156.4	105.0	161.7	406.8	131.6	168.2	185.5
La	16.6	136.7	16.0	11.3	10.0	17.4	10.7	13.5	18.2
Ce	39.8	279.1	31.6	15.1	21.9	21.7	23.4	23.3	30.0
Nd	26.1	138.0	21.0	9.0	15.8	25.1	20.2	22.2	21.3
Nb	10.6	42.5	12.3	7.4	12.1	4.0	9.3	12.3	14-1
Zr	167.2	445.5	138.1	78.5	128.8	154.2	94.1	152.1	151.2
Y	38.3	50.0	28.3	17.2	26.4	39.5	23.3	34.2	36.4
Sr	401.4	3244.1	326.3	325.6	345.6	341.6	297.0	279.7	280.6
Rь	20.3	195.7	13.3	5.9	12.9	6.9	10.2	12.0	14.4
Th	4.4	11.5	3.7	0.1	0.4	0.1	3.3	1.0	2.0
Ga	25.9	22.2	20.9	20.3	22.7	23.3	22.1	23.1	23.U
Zn	120.0	174.5	114.3	106.1	103.8	156.8	93.0	102.1	113.1
Ni	41.5	176.4	142.7	187.8	86.3	77.5	95.B	84.8	54.8

#### METAGABBROS & ULTRAMAFIC SAMPLES

Name	DMSH102B	DMSH1B	DMSH4F	DMSH4G	DMSS1A	DMSS18	DMSS1C	DMSH101A	DMSH101B
S102	47.83	45.58	46.46	46.14	46.04	44.44	47.43	45.41	43.70
T102	0.35	2.18	2.77	2.21	1.84	4.46	1.59	2.23	4.44
A1203	13.93	18.83	17.57	16.80	17.00	13.62	15.24	16.25	15.91
Fe203	1.59	3.10	2.30	2.56	2.62	3.08	2.46	3.20	2.70
Fe0	6.35	9.20	10.60	10.22	10.47	12.32	9.82	11.20	12.70
MnO	0.14	0.17	0.17	0.17	0.17	0.21	0.20	0.23	0.20
MgO	13.56	4.86	6.65	8.32	8.62	6.34	6.74	7.02	6.07
CaO	14.16	9.21	8.41	8.17	8.59	10.17	9.62	9.53	8.35
Na20	1.19	3.47	3.20	2.64	2.96	3.11	2.70	3.22	3.02
K20	0.02	0.74	0.73	0.73	0.94	0.05	1.03	0.62	0.81
P205	0.04	0.52	0.33	0.32	0.21	0.19	0.36	0.23	0.35
Total	99.15	97.86	99.19	98.10	99.46	97.99	97.19	99.14	98.25
CIPW	Norms								
Or	0.12	4.37	4.31	4.31	5.56	0.30	6.09	3.66	4.79
АЪ	10.07	26.59	27.08	22.34	22.64	26.32	22.85	22.19	25.25
An	32.62	33.63	31.43	31.84	30.33	23.06	26.43	28.06	21.41
Ne		1.07			1.30			2.51	U.+2 D C2
Di	29.87	7.15	6.67	5.38	8.91	21.50	15.57	14.57	3.03
Ну	7.95		3.19	10.55		0.06	7.75	40.00	10 01
01	15.48	14.42	17.14	15.21	22.95	13.37	11.08	10.34	2 91
Mt	2.30	4.49	3.33	3.70	3.80	4.45	3.36	4.04	8 13
Ilm	0.66	4.14	5.26	4.20	3.49	8.47	3.02	9.69	0.43
Ap	0.09	1.20	0.76	0.74	0.49	0.44	<b>U.8</b> 3	0.55	0.01
Trace	elements i	in ppm.							
Cr	708.5	41.3	273.3	223.8	50.8	105.1	209.8	63.4	130.3
v	148.4	290.8	276.7	174.2	182.5	779.1	269.2	264.0	346.4
Ba	19.6	450.6	289.9	266.4	298.7	46.8	661.4	94.2	331.2
La	0.7	14.2	7.2	14.4	10.5	8.9	18.9	11.8	13.0
Ce	0.1	29.3	25.1	22.3	27.3	18.7	45.5	21.5	31.5
Nd	3.3	22.9	13.5	15.5	17.4	15.3	30.6	17.3	22.J
NЪ	3.0	4.0	7.7	8.8	10.2	12.9	6.0	11.0	9.6
Zr	22.1	133.2	90.6	109.0	111.3	110.4	148.7	132.3	131.1
Y	11.7	31.5	21.2	23.3	25.4	33.2	35.7	32.5	20.2
Sr	207.7	500.5	507.4	460.0	366.3	212.4	408.7	255.8	401.0
RЬ	4.0	11.2	9.5	13.4	21.7	0.4	24.7	7.7	14.3
Th	0.5	1.5	2.9	0.1	4.5	6.0	5.1	1.0	2.1
Ga	11.6	24.3	20.3	19.8	21.8	32.1	23.3	410 0	29.J 110 7
Zn	60.8	126.1	102.0	108.7	123.4	117.1	124.0	113.8	65 9
N1	141.2	68.4	95.3	154.7	156.9	86.3	41.J	33.1	

Name	DMSH101C	DMSH101D	DMSR9	DMSR11	DMSR22	DMSR28	DMSR30	DMSR318	DMSR82
S102	45.23	46.52	45.13	44.97	44.87	46.23	45.12	46.98	46.30
T102	3.80	2.81	3.04	3.34	3.85	2.23	2.69	1.47	2.08
A1203	16.18	18.22	16.12	17.55	15.63	18.14	17.63	17.65	17.01
Fe203	2.50	1.90	3.07	4.10	3.03	2.50	2.78	2.39	2.80
Fe0	12.00	11.00	12.27	9.70	12.10	10.01	11.13	9.57	10.40
MnO	0.20	0.17	0.21	0.17	0.21	0.16	0.18	0.17	0.17
MaD	5.65	6.03	5.87	6.30	5.59	7.73	6.25	7.10	9.82
CaO	8.22	8.67	8.41	8.36	7.97	8.27	7.71	10.72	7.73
Na20	3.59	3.54	3.65	3.29	3.41	2.95	3.57	2.80	2.93
K20	1.05	0.86	0.71	0.86	1.13	0.70	0.83	0.32	0.67
P205	0.44	0.42	0.47	0.36	0.65	0.34	0.38	0.14	0.34
Total	98.86	100.00	98.95	99.00	98.44	99.27	98.27	99.32	100.25
CIPW	Norms								
Or	6.21	5.08	4.20	5.08	6.68	4.14	4.91	1.89	3.96
Ab	26.41	27.48	26.59	25.65	27.51	24.96	27.02	23.69	24.79
An	24.94	31.29	25.51	30.59	24.01	34.20	29.64	34.66	31.29
Ne	2.43	1.62	2.33	0.27	0.73		1.73		
Di	10.73	7.43	10.89	6.94	9.33	3.76	5.05	14.44	3.93
Hy						5.25		1.60	4.31
01	16.81	18.83	18.13	15.66	16.98	18.31	19.91	16.45	23.18
Mt	3.62	2.68	4.45	5.94	4.39	3.63	4.03	3.47	4.06
Ilm	7.22	5.34	5.77	6.34	7.31	4.24	5.11	2.79	3.95
Ap	1.02	0.97	1.09	0.83	1.51	0.79	0.88	0.32	0.79
Trace	elements	in ppm.							405 4
Cr	48.9	30.2	45.6	31.5	120.6	51.1	215.2	136.7	105.1
V	291.3	199.3	237.0	251.3	236.8	137.4	227.3	208.1	132.6
Ba	398.4	344.5	324.3	326.6	444.6	280.3	313.1	127.2	268.4
La	16.6	11.7	14.6	10.1	19.3	10.0	9.8	5.7	2.1
Ce	30.6	30.4	39.3	28.7	47.3	27.6	27.7	16.1	20.9
Nd	22.0	19.2	29.0	18.7	33.2	18.1	19.2	10.7	10.3
Nb	11.5	10.4	13.2	8.8	13.3	8.2	8.7	5./ 70.5	400.3
Zr	165.9	148.9	190.1	113.3	206.1	106.5	121.8	18.5	100.2
Y	31.5	27.3	36.4	25.2	39.2	21.8	25.4	19.4	22.0
Sr	480.5	588.7	464.9	574.6	476.3	643.3	568.8	301.3	2/1.8
RЬ	17.0	14.6	8.8	13.5	14.6	9.0	8.6	5.1	0.0
Th	0.6	2.2	7.8	4.8	3.0	4.8	3.5	<b>3.3</b>	3.3
Ga	22.2	22.1	24.6	23.1	26.4	21.8	22.8	22.1	109 0
Zn	122.5	115.1	123.7	96.6	125.2	110.1	118.0	32.8 87 7	212 0
Ni	55.4	85.2	62.4	101.7	73.6	152.0	84.2	06.6	

#### METAGABBROS & MAFIC SAMPLES

Name	DMSD38B	DMSD48A	DMSD68	DMSD68A	DMSD62C	DMSK2	DMSK4	DMSK5	DMSK10
\$i02	46.79	46.82	46.34	46.45	47.81	45.34	52.21	46.73	45.49
T102	2.60	3.12	2.81	2.32	0.83	3.08	1.01	2.06	2.02
A1203	15.90	16.57	17.96	17.61	19.68	17.13	15.97	18.41	17.00
Fe203	2.86	2.75	2.90	3.00	3.80	2.78	2.10	2.33	2.20
Fe0	11.43	10.99	10.20	10.20	6.20	11.14	8.42	9.30	11.30
MnD	0.20	0.19	0.17	0.17	0.14	0.17	0.18	0.17	0.18
MgQ	6.38	5.80	6.43	6.53	8.92	6.07	6.60	6.54	8.83
CaO	8.84	8.16	8.37	8.28	9.99	7.92	8.08	10.40	7.89
Na20	3.23	3.50	3.67	3.59	2.35	3.40	2.71	2.87	3.22
K20	0.80	1.11	0.92	0.85	0.37	0.92	1.27	0.54	0.69
P205	0.61	0.51	0.47	0.45	0.27	0.48	0.11	0.25	0.33
Total	99.64	99.51	100.24	99.45	100.36	98.43	98.66	99.60	99.15
CIPW	Norma								
Qtz							1.63		
Or	4.73	6.56	5.44	5.02	2.19	5.44	7.51	3.19	4.08
АЪ	27.33	29.62	26.87	27.78	19.89	28.01	22.93	24.29	25.00
An	26.53	26.23	29.82	29.44	42.07	28.77	27.67	35.77	29.90
Ne			2.05	1.17		0.41			1.54
Di	11.01	9.00	7.07	7.16	4.59	6.08	9.59	11.63	5.80
Hy	3.97	0.14			15.70		24.12	1.11	
01	15.58	16.87	17.96	18.66	8.23	18.73		15.76	25.64
Mt	4.14	3.98	4.20	4.35	5.51	4.04	3.05	3.37	3.19
Ilm	4.94	5.93	5.34	4.41	1.58	5.85	1.92	3.91	3.84
Ap	1.41	1.18	1.09	1.04	0.63	1.11	0.25	0.58	0.76
Trace	elements	in ppm.							400 0
Cr	196.6	157.4	29.1	115.6	224.6	157.9	20.0	59.9	100.0
V	305.8	209.7	180.8	171.5	144.4	255.7	194.8	233.5	146.1
Ba	434.8	399.0	358.4	334.7	303.0	354.7	180.1	156.1	20.0
La	12.8	14.5	15.8	12.5	5.6	10.2	17.4	13.5	3.4
Ce	36.5	40.9	34.7	35.9	17.3	34.2	41.3	34.0	47 0
Nd	26.3	27.3	23.5	23.8	11.0	22.6	21.5	21.1	7.0
NЬ	5.1	12.0	10.6	9.7	2.4	9.4	6.0	12.1	404 4
Zr	160.8	156.2	148.5	140.0	32.7	136.2	145.5	137.1	104.4
Y	40.5	33.7	29.4	28.4	16.5	26.3	33.9	28.4	21.3
Sr	401.3	474.1	593.4	607.8	528.2	566.3	208.3	340.4	480.0
RЪ	10.6	19.4	11.8	9.5	3.1	11.6	31.3	11.1	8.1
Th	4.4	5.9	5.0	6.2	2.3	4.3	7.9	3.5	3.8
Ga	26.1	25.6	24.7	24.6	18.5	24.8	18.3	23.4	41.9
Zn	143.2	109.1	109.8	109.5	91.1	115.8	93.2	112.3	110.0
Ni	108.6	71.9	101.3	96.7	115.7	82.7	54.7	113.3	103.4

#### METAGABBROS & MAFIC SAMPLES

Name	DMSK13	DM237A	DMSP2	84A-81	DMSR78A	DMSR38	DMSR44C	DMSR48A	DMSR50A
Si02	46.23	47.80	49.21	49.46	47.93	43.33	49.22	45.31	44.83
Ti02	1.90	1.45	0.66	1.10	1.45	4.68	0.48	1.88	2.30
A1203	17.45	18.60	16.15	15.84	17.14	12.93	11.45	17.23	16.46
Fe203	2.80	4.60	1.80	2.13	2.26	3.53	1.83	2.61	2.80
Fe0	9.40	8.10	7.21	8.51	9.05	14.14	7.33	10.45	11.20
MnQ	0.18	0.18	0.15	0.18	0.17	0.25	0.17	0.20	0.22
MgD	8.03	6.46	9.11	8.04	6.66	5.93	13.22	7.50	7.20
CaO	10.19	9.36	13.06	10.99	10.25	10.49	13.80	9.64	9.40
Na20	2.65	3.21	2.73	2.81	3.55	2.92	1.24	3.10	2.82
K20	0.44	0.45	0.37	0.38	0.49	0.19	0.72	0.47	1.44
P205	0.21	0.30	0.04	0.27	0.52	0.17	0.11	0.22	0.34
Total	99.48	100.51	100.49	99.70	99.47	98.56	99.57	98.61	99.01
CIPW	Norms								
Ûr	2.60	2.66	2.19	2.23	2.90	1.12	4.26	2.78	8.51
AЪ	22.42	27.16	19.63	23.78	27.87	22.03	10.49	22.26	16.78
An	34.43	35.02	30.73	29.50	29.40	21.62	23.56	31.72	28.01
Ne			1.88		1.17	1.45		2.15	3.84
Di	12.01	7.68	27.34	18.95	14.81	24.31	35.45	12.03	13.49
Hy	2.68	8.58		9.48			8.18		
01	17.18	9.29	14.77	9.96	16.09	13.63	13.82	19.81	19.18
Mt	4.06	6.67	2.61	3.08	3.28	5.13	2.66	3.79	4.00
Ilm	3.61	2.75	1.25	2.09	2.75	8.89	0.91	3.57	4.31
Ap	0.49	0.70	0.09	0.63	1.20	0.39	0.25	0.51	0.75
Trace	elements	in ppm.							~ ~
Cr	79.7	172.4	297.1	268.8	162.6	76.5	715.5	51.5	09.2
v	224.4	202.1	181.4	250.8	231.8	886.0	212.6	181.8	400 5
Ba	139.6	320.3	161.8	151.3	522.4	17.2	211.3	71.0	103.5
La	9.7	5.1	3.8	6.9	19.2	6.7	6.7	1.8	20.0
Ce	27.0	20.3	11.6	12.3	54.6	16.2	15.6	21.5	20.1
Nd	17.0	10.7	6.0	8.7	38.7	10.3	13.7	10.0	23.1
NЬ	11.0	3.0	1.6	2.8	6.0	9.9	2.1	10.0	126 7
Zr	114.5	61.6	15.5	57.7	115.1	99.6	25.5	113.0	120.1
Y	26.2	20.1	12.1	23.4	34.7	29.1	16.9	23.2	215 5
Sr	326.6	507.6	460.8	339.1	796.4	130.6	302.3	67	275
RЬ	8.1	3.5	8.5	5.8	1.8	2.1	30.3	0.1 4 E	1.3
Th	3.6	3.6	3.8	1.3	5.0	6.2	5.1	1.3	7.J 25 L
Ga	22.9	24.2	17.8	19.9	23.4	30.5	73.5	405 C	145 6
Zn	105.1	115.4	70.6	87.4	132.9	150.2	10.4	111 2	2 19
Ni	168.3	98.8	85.7	70.2	60.4	51.7	33.6	(14.3	20.0

#### MAFIC AND ULTRAMAFIC SAMPLES

S102       45.49       46.62       41.20       47.45       42.04       45.08       50.47       47.83       37.70         T102       3.55       4.61       2.02       0.84       0.71       0.42       0.64       0.35       4.95         A1203       14.71       17.04       14.71       17.54       8.08       14.33       7.29       13.93       16.68         F=203       3.19       2.72       3.21       2.25       2.88       2.27       1.63       1.59       4.49         F=0       12.75       10.86       12.85       9.00       11.50       9.09       7.31       6.35       17.95         Mn0       0.23       0.19       0.17       0.18       0.21       0.17       0.19       0.14       0.65         Mg0       4.50       4.31       9.81       7.49       26.02       19.10       14.19       13.56       2.64         Ca0       7.96       7.86       12.35       10.99       4.94       7.61       15.26       14.16       10.67         Na20       3.67       4.40       1.11       2.13       0.28       1.17       1.38       1.19       1.61         K20       <
Sing       Give       Give <thgive< th="">       Give       Give</thgive<>
A1203       14.71       17.04       14.71       17.54       8.08       14.39       7.29       13.93       16.68         Fe203       3.19       2.72       3.21       2.25       2.88       2.27       1.63       1.59       4.49         Fe0       12.75       10.86       12.85       9.00       11.50       9.09       7.31       6.35       17.95         Mn0       0.23       0.19       0.17       0.18       0.21       0.17       0.19       0.14       0.65         Mg0       4.50       4.31       9.81       7.49       26.02       19.10       14.19       13.56       2.64         Ca0       7.96       7.86       12.35       10.99       4.94       7.61       15.26       14.16       10.67         Na20       3.67       4.40       1.11       2.13       0.28       1.17       1.38       1.19       1.61         K20       1.23       0.66       0.38       0.58       0.20       0.55       0.78       0.02       0.58         P205       1.05       0.51       0.10       0.05       0.14       0.13       0.08       0.04       0.88         Total       98.3
F=203 3.19 2.72 3.21 2.25 2.88 2.27 1.83 1.59 4.49 F=0 12.75 10.86 12.85 9.00 11.50 9.09 7.31 6.35 17.95 Mn0 0.23 0.19 0.17 0.18 0.21 0.17 0.19 0.14 0.65 Mg0 4.50 4.31 9.81 7.49 26.02 19.10 14.19 13.56 2.64 CaO 7.96 7.86 12.35 10.99 4.94 7.61 15.26 14.16 10.67 N=20 3.67 4.40 1.11 2.13 0.28 1.17 1.38 1.19 1.61 K20 1.23 0.66 0.38 0.58 0.20 0.55 0.78 0.02 0.58 P205 1.05 0.51 0.10 0.05 0.14 0.13 0.08 0.04 0.88 Total 98.33 99.78 97.92 98.50 97.00 99.98 99.42 99.15 98.80 CIPW Norms Or 7.27 3.90 2.25 3.43 1.18 3.25 4.61 0.12 3.43 Ab 30.73 34.35 6.30 18.02 2.37 9.90 11.68 10.07 13.26 An 20.04 24.80 34.04 36.59 20.20 32.40 11.40 32.62 36.58 Ne 0.18 1.56 1.68 0.19 Di 10.53 8.97 21.77 14.41 2.70 3.60 51.06 29.87 9.12 Hy 9.84 22.35 11.31 2.63 7.95 Ol 15.79 12.32 23.17 11.23 42.35 35.14 13.99 15.48 18.27 Mt 4.62 3.94 4.66 3.26 4.17 3.29 2.65 2.30 6.51 Ilm 6.74 8.76 3.84 1.60 1.35 0.80 1.22 0.66 9.40 An 2.43 1.18 0.23 0.12 0.32 0.30 0.19 0.09 2.04
FeO       12.75       10.86       12.85       9.00       11.50       9.09       7.31       6.35       17.95         MnD       0.23       0.19       0.17       0.18       0.21       0.17       0.19       0.14       0.655         MgO       4.50       4.31       9.81       7.49       26.02       19.10       14.19       13.56       2.64         CaO       7.96       7.86       12.35       10.99       4.94       7.61       15.26       14.16       10.67         Na20       3.67       4.40       1.11       2.13       0.28       1.17       1.38       1.19       1.61         K20       1.23       0.66       0.38       0.58       0.20       0.55       0.78       0.02       0.58         P205       1.05       0.51       0.10       0.05       0.14       0.13       0.08       0.04       0.88         Total       98.33       99.78       97.92       98.50       97.00       99.98       99.42       99.15       98.80         CIPW       Norms       0.73       34.35       6.30       18.02       2.37       9.90       11.68       10.07       13.26 <t< td=""></t<>
$\begin{array}{cccccccccccccccccccccccccccccccccccc$
Mg0       4.50       4.31       9.81       7.49       26.02       19.10       14.19       13.56       2.64         Ca0       7.96       7.86       12.35       10.99       4.94       7.61       15.26       14.16       10.67         Na20       3.67       4.40       1.11       2.13       0.28       1.17       1.38       1.19       1.61         K20       1.23       0.66       0.38       0.58       0.20       0.55       0.78       0.02       0.58         P205       1.05       0.51       0.10       0.05       0.14       0.13       0.08       0.04       0.88         Total       98.33       99.78       97.92       98.50       97.00       99.98       99.42       99.15       98.80         CIPW       Norms       0.7       7.27       3.90       2.25       3.43       1.18       3.25       4.61       0.12       3.43         Ab       30.73       34.35       6.30       18.02       2.37       9.90       11.68       10.07       13.26         An       20.04       24.80       34.04       36.59       20.20       32.40       11.40       32.62       36.58 </td
Ng0       1.131       1.131       1.141       1.132       10.99       4.94       7.61       15.26       14.16       10.67         Na20       3.67       4.40       1.11       2.13       0.28       1.17       1.38       1.19       1.61         K20       1.23       0.66       0.38       0.58       0.20       0.55       0.78       0.02       0.58         P205       1.05       0.51       0.10       0.05       0.14       0.13       0.08       0.04       0.89         Total       98.33       99.78       97.92       98.50       97.00       99.98       99.42       99.15       98.80         CIPW Norms       0       7.27       3.90       2.25       3.43       1.18       3.25       4.61       0.12       3.43         Ab       30.73       34.35       6.30       18.02       2.37       9.90       11.68       10.07       13.26         An       20.04       24.80       34.04       36.59       20.20       32.40       11.40       32.62       36.58         Ne       0.18       1.56       1.68          0.19       0.19       9.12
Na20       3.67       4.40       1.11       2.13       0.28       1.17       1.38       1.19       1.61         K20       1.23       0.66       0.38       0.58       0.20       0.55       0.78       0.02       0.58         P205       1.05       0.51       0.10       0.05       0.14       0.13       0.08       0.04       0.89         Total       98.33       99.78       97.92       98.50       97.00       99.98       99.42       99.15       98.80         CIPW Norms       0.04       2.25       3.43       1.18       3.25       4.61       0.12       3.43         Ab       30.73       34.35       6.30       18.02       2.37       9.90       11.68       10.07       13.26         An       20.04       24.80       34.04       36.59       20.20       32.40       11.40       32.62       36.58         Ne       0.18       1.56       1.68          0.19         D1       10.53       8.97       21.77       14.41       2.70       3.60       51.06       29.87       9.12         Hy         9.84       22.35
K20       1.23       0.66       0.38       0.58       0.20       0.55       0.78       0.02       0.58         P205       1.05       0.51       0.10       0.05       0.14       0.13       0.08       0.04       0.88         Total       98.33       99.78       97.92       98.50       97.00       99.98       99.42       99.15       98.80         CIPW Norms       0r       7.27       3.90       2.25       3.43       1.18       3.25       4.61       0.12       3.43         Ab       30.73       34.35       6.30       18.02       2.37       9.90       11.68       10.07       13.26         An       20.04       24.80       34.04       36.59       20.20       32.40       11.40       32.62       36.58         Ne       0.18       1.56       1.68         0.19         Di       10.53       8.97       21.77       14.41       2.70       3.60       51.06       29.87       9.12         Hy         9.84       22.35       11.31       2.63       7.95          01       15.79       12.32       23.17       11.2
N20       1.123       0.103       0.101       0.05       0.14       0.13       0.08       0.04       0.88         P205       1.05       0.51       0.10       0.05       0.14       0.13       0.09       0.04       0.88         Total       98.33       99.78       97.92       98.50       97.00       99.98       99.42       99.15       98.80         CIPW       Norms       0r       7.27       3.90       2.25       3.43       1.18       3.25       4.61       0.12       3.43         Ab       30.73       34.35       6.30       18.02       2.37       9.90       11.68       10.07       13.26         An       20.04       24.80       34.04       36.59       20.20       32.40       11.40       32.62       36.58         Ne       0.18       1.56       1.68          0.19         D1       10.53       8.97       21.77       14.41       2.70       3.60       51.06       29.87       9.12         Hy         9.84       22.35       11.31       2.63       7.95          01       15.79       12.32
Total98.3399.7897.9298.5097.0099.9899.4299.1598.80CIPWNorms $0r$ 7.273.902.253.431.183.254.610.123.43Ab30.7334.356.3018.022.379.9011.6810.0713.26An20.0424.8034.0436.5920.2032.4011.4032.6236.58Ne0.181.561.680.19D110.538.9721.7714.412.703.6051.0629.879.12Hy9.8422.3511.312.637.950115.7912.3223.1711.2342.3535.1413.9915.4818.27Mt4.623.944.663.264.173.292.652.306.51IIm6.748.763.841.601.350.801.220.669.40
CIPW Norms         Or       7.27       3.90       2.25       3.43       1.18       3.25       4.61       0.12       3.43         Ab       30.73       34.35       6.30       18.02       2.37       9.90       11.68       10.07       13.26         An       20.04       24.80       34.04       36.59       20.20       32.40       11.40       32.62       36.58         Ne       0.18       1.56       1.68         0.19         Di       10.53       8.97       21.77       14.41       2.70       3.60       51.06       29.87       9.12         Hy         9.84       22.35       11.31       2.63       7.95          01       15.79       12.32       23.17       11.23       42.35       35.14       13.99       15.48       18.27         Mt       4.62       3.94       4.66       3.26       4.17       3.29       2.65       2.30       6.51         IIm       6.74       8.76       3.84       1.60       1.35       0.80       1.22       0.66       9.40
CIPW       Norms         Or       7.27       3.90       2.25       3.43       1.18       3.25       4.61       0.12       3.43         Ab       30.73       34.35       6.30       18.02       2.37       9.90       11.68       10.07       13.26         An       20.04       24.80       34.04       36.59       20.20       32.40       11.40       32.62       36.58         Ne       0.18       1.56       1.68          0.19         Di       10.53       8.97       21.77       14.41       2.70       3.60       51.06       29.87       9.12         Hy         9.84       22.35       11.31       2.63       7.95          01       15.79       12.32       23.17       11.23       42.35       35.14       13.99       15.48       18.27         Mt       4.62       3.94       4.66       3.26       4.17       3.29       2.65       2.30       6.51         Ilm       6.74       8.76       3.84       1.60       1.35       0.80       1.22       0.66       9.40
$\begin{array}{cccccccccccccccccccccccccccccccccccc$
Ab       30.73       34.35       6.30       18.02       2.37       9.90       11.68       10.07       13.26         An       20.04       24.80       34.04       36.59       20.20       32.40       11.40       32.62       36.58         Ne       0.18       1.56       1.68          0.19         Di       10.53       8.97       21.77       14.41       2.70       3.60       51.06       29.87       9.12         Hy        9.84       22.35       11.31       2.63       7.95          01       15.79       12.32       23.17       11.23       42.35       35.14       13.99       15.48       18.27         Mt       4.62       3.94       4.66       3.26       4.17       3.29       2.65       2.30       6.51         Ilm       6.74       8.76       3.84       1.60       1.35       0.80       1.22       0.66       9.40
An       20.04       24.80       34.04       36.59       20.20       32.40       11.40       32.62       36.58         Ne       0.18       1.56       1.68          0.19         D1       10.53       8.97       21.77       14.41       2.70       3.60       51.06       29.87       9.12         Hy        9.84       22.35       11.31       2.63       7.95          01       15.79       12.32       23.17       11.23       42.35       35.14       13.99       15.48       18.27         Mt       4.62       3.94       4.66       3.26       4.17       3.29       2.65       2.30       6.51         Ilm       6.74       8.76       3.84       1.60       1.35       0.80       1.22       0.66       9.40
Ne         0.18         1.56         1.68           0.19           Di         10.53         8.97         21.77         14.41         2.70         3.60         51.06         29.87         9.12           Hy          9.84         22.35         11.31         2.63         7.95            01         15.79         12.32         23.17         11.23         42.35         35.14         13.99         15.48         18.27           Mt         4.62         3.94         4.66         3.26         4.17         3.29         2.65         2.30         6.51           Ilm         6.74         8.76         3.84         1.60         1.35         0.80         1.22         0.66         9.40           A2         2.43         1.18         0.23         0.12         0.30         0.19         0.09         2.04
Di       10.53       8.97       21.77       14.41       2.70       3.60       51.06       29.87       9.12         Hy         9.84       22.35       11.31       2.63       7.95          01       15.79       12.32       23.17       11.23       42.35       35.14       13.99       15.48       18.27         Mt       4.62       3.94       4.66       3.26       4.17       3.29       2.65       2.30       6.51         Ilm       6.74       8.76       3.84       1.60       1.35       0.80       1.22       0.66       9.40
Hy         9.84       22.35       11.31       2.63       7.95          01       15.79       12.32       23.17       11.23       42.35       35.14       13.99       15.48       18.27         Mt       4.62       3.94       4.66       3.26       4.17       3.29       2.65       2.30       6.51         Ilm       6.74       8.76       3.84       1.60       1.35       0.80       1.22       0.66       9.40         A2       2.43       1.18       0.23       0.12       0.32       0.30       0.19       0.09       2.04
01       15.79       12.32       23.17       11.23       42.35       35.14       13.99       15.48       18.27         Mt       4.62       3.94       4.66       3.26       4.17       3.29       2.65       2.30       6.51         Ilm       6.74       8.76       3.84       1.60       1.35       0.80       1.22       0.66       9.40         A2       2.43       1.18       0.23       0.12       0.32       0.30       0.19       0.09       2.04
Mt         4.62         3.94         4.66         3.26         4.17         3.29         2.65         2.30         6.51           Ilm         6.74         8.76         3.84         1.60         1.35         0.80         1.22         0.66         9.40           Ac         2.43         1.18         0.23         0.12         0.32         0.30         0.19         0.09         2.04
IIm         6.74         8.76         3.84         1.60         1.35         0.80         1.22         0.66         9.40           Ac         2.43         1.18         0.23         0.12         0.32         0.30         0.19         0.09         2.04
An 2.43 1 18 0.23 0.12 0.32 0.30 0.19 0.09 2.04
Trace elements in ppm.
Cr 30.0 22.3 330.5 120.0 1867.6 1286.2 879.0 708.5 38.9
V 243.5 256.0 474.8 386.0 116.0 83.3 238.9 148.4 89.0
Ba 740.5 217.5 188.2 154.2 112.4 271.7 191.7 19.6 124.3
La 20.8 17.0 4.5 3.9 1.0 7.0 6.2 0.7 13.6
Ce 57.6 32.8 11.8 13.1 4.6 16.7 17.0 0.1 31.0
Nd 40.7 25.6 9.9 7.7 4.7 9.9 15.3 3.3 23.0
Nb 7.9 12.0 3.5 4.1 1.8 1.4 2.3 3.0 24.8
Zr 220.0 153.4 20.3 14.7 34.1 52.8 60.5 22.1 42.7
Y 57.3 31.4 12.3 14.3 11.8 10.6 25.5 11.7 78.7
Sr 455.6 827.1 823.9 453.4 166.7 481.7 152.7 207.7 266.0
Rb 20.0 6.1 5.1 17.7 1.1 9.9 19.1 4.0 20.3
Th 4.7 3.6 2.4 4.6 3.8 3.1 5.0 0.5 6.8
Ga 27.6 27.5 21.4 20.6 10.8 13.1 12.0 11.6 23.9
Zn 168.0 104.4 102.2 91.3 117.7 100.9 92.2 60.8 209.5
Ni 37.3 33.0 113.1 14.8 1075.4 400.7 289.0 141.2 7.5

#### HOST GNEISS & GRANULITE

Name	DMS125C	DMS-17C	DMS-91E	DMS-105	DMS-103	DMS-115	DMSA-17	DMSA-92	DMSR-12
Si02	67.56	68.01	72.38	54.74	64.50	69.74	51.14	73.44	53.83
Ti02	0.35	0.70	0.14	0.94	0.81	0.39	1.75	0.28	0.18
A1203	17.52	14.95	13.91	20.08	16.07	15.38	15.93	13.67	28.43
Fe203	0.22	0.49	0.14	0.94	0.78	0.41	1.61	0.19	0.12
Fe0	1.48	3.28	0.92	6.26	5.19	2.75	10.72	1.27	0.79
MnO	0.02	0.07	0.02	0.14	0.11	0.06	0.22	0.03	0.10
MgQ	0.57	1.22	0.41	1.92	1.17	0.74	3.82	0.47	0.13
CaO	2.26	2.34	1.00	6.17	3.40	2.45	8.08	1.28	10.69
Na20	6.55	4.06	2.19	4.56	3.99	3.83	3.98	3.55	5.45
K20	3.39	3.57	8.69	1.97	3.70	4.33	1.27	4.94	0.45
P205	0.20	0.30	0.03	0.26	0.34	0.11	0.58	0.21	0.06
Total	100.12	98.99	99.83	97.98	100.06	100.20	99.10	99.33	100.23
CIPW	Norms								
Qtz	10.78	22.64	23.58	1.12	15.53	22.94		30.20	
Car		0.87			0.14	0.20		0.65	
Or	20.02	21.12	51.36	11.64	21.86	25.59	7.52	29.21	2.66
Аb	55.43	34.36	18.53	38.59	33.76	32.41	33.68	30.04	40.39
An	8.41	9.64	2.47	28.51	14.65	11.44	21.85	5.00	51.80
Ne									3.10
Di	1.25		1.92	0.33			12.16		0.73
Hy	2.79	7.63	1.44	14.04	10.67	6.03	9.96	2.94	
01							6.94		0.91
Mt	0.32	0.71	0.20	1.36	1.13	0.60	2.33	0.28	0.17
Ilm	0.66	1.33	0.27	1.79	1.54	0.74	3.32	0.53	0.34
Aρ	0.46	0.70	0.07	0.60	0.79	0.25	1.34	0.48	0.14
Trace	elements	in ppm.							
Cr	3.0	3.8	9.7	12.0	10.4	6.5	38.3	3.9	12.8
V	14.5	38.0	2.7	95.5	53.6	37.6	166.9	14.5	15.5
Ba	1597.2	1403.7	1236.3	1295.3	1346.9	1263.0	348.8	856.9	185.8
La	103.8	28.8	2.6	25.0	45.9	54.0	29.2	32.0	0.7
Ce	186.0	56.0	5.0	49.6	92.5	106.0	64.8	61.5	2.1
Nd	58.6	28.4	3.5	26.2	40.7	41.9	42.U	22.6	<u>.</u>
NЬ	6.7	6.7	13.4	16.2	15.6	5.3	12.4	3.5	0.0
Zr	247.2	222.6	18.8	331.2	305.5	174.8	189.5	136.7	2.1
Y	12.0	29.6	27.2	24.6	44.0	18.1	64.0	15.5	J.2
Sr	389.0	569.2	182.1	590.0	315.2	219.7	434.9	196.2	2.5CB
RЬ	71.5	39.5	265.4	50.1	86.5	63.3	7.5	123.2	3.1
Th	22.2	2.4	2.2	7.9	6.8	8.4	0.5	8.5	10
Ga	24.6	16.5	15.0	23.8	19.7	15.7	28.8	15.7	10.4
Zn	33.9	65.0	18.1	99.2	99.6	43.5	183.5	+U.D	10.3
Ni	17.7	7.5	3.2	6.9	5.9	4.1	27.8	0.2	4.3

#### ANORTHOSITIIC GNEISS

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Name	DMSR-13	DMSR-45	i DMS-38	DMS-182	85DMS3	85DMS5	85DMS9A	DMSN2A	DMSH99
S102	54.56	55.11	52.71	56.79	52.28	53.19	54.00	51.87	52.21
T102	0.11	0.11	0,12	0.15	0.19	0.14	0.08	0.19	0.17
A1203	28.67	28.47	30.43	25.71	28.32	28.11	29.00	28.14	28.58
Fe203	0.08	0.09	0.15	D.17	0.16	0.18	0.06	0.30	0.21
FeO	0.52	0.60	0.98	1.16	1.06	1.21	0.40	2.03	1.39
MnO	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.04	0.02
MgQ	0.01	0.12	0.46	0.32	0.26	1.19	0.10	0.95	0.78
CaD	10.58	9.49	12.03	8.19	11.15	10.55	10.70	11.62	11.77
Na20	5.43	5.36	4.17	6.04	5.12	5.41	5.30	4.63	4.31
K20	0.45	1.21	0.54	1.18	0.28	0.71	0.28	0.44	0.49
P205	0.03	0.03	0.03	0.06	0.05	0.03	0.03	0.04	0.04
Total	100.45	100.59	101.63	99.79	98.88	100.75	99.96	100.26	99.97
CIPW	Norma								
Cor	0.09	1.17	1.19	~~			0.60		
Or	2.66	7.15	3.19	6.97	1.65	4.20	1.65	2.60	2.90
Ab	42.65	42.66	35.29	49.34	37.42	35.65	42.78	33.30	34.70
An	52.29	46.88	59.48	39.57	53.48	50.33	52.88	54.71	57.20
Ne	1.79	1.46		0.96	3.20	5.49	1.12	3.18	0,96
Di				0.57	1.28	1.47		2.23	0,77
Ну			0.02						~~
01	0.58	0.87	1.96	1.71	1.15	3.01	0.61	3,33	2.13
Mt	0.11	0.13	0.21	0.25	0.23	0.26	0.09	U.44	0.30
Ilm	0.21	0.21	0.23	0.28	0.36	0.27	0.15	0,35	0.32
Ap	0.07	0.07	0.07	0.14	0.12	0.07	0.07	0.09	0,03
Trace	elements	in ppm.							
Cr	28.7	1.5	30.4	2.0	45.7	57.2	17.2	34.9	40.9
v	6.0	5.2	14.3	6.3	24.8	15.3	3.8	6.5	22/ 2
Ba	182.9	218.7	124.4	243.2	160.1	185.8	151.3	289.4	224.3
La	1.2	2.4	0.7	6.0	3.3	1.0	1.4	2.5	u.i
Ce 👘	2.7	1.6	2.4	10.5	0.1	1.2	2.7	1.3	2.0
Nd	2.2	2.3	2.9	5.2	7.5	0.3	3.0	3.1	3. <del>1</del> 2 0
NЬ	1.6	0.6	0.8	1.9	1.0	0.1	1.0	2.8	12 2
Zr	0.1	0.1	0.1	40.3	0.1	0.1	0.1	2.2	12.3
Y	2.0	2.1	1.8	3.6	3.6	1.8	1.1	J.J 505 0	5.0
Sr	866.7	928.8	554.6	733.0	770.0	768.7	818.1	0.CLC	7 7
Rb	4.8	20.9	8.0	12.4	4.4	11.4	2.2	4.2	1.2
Th	2.9	1.6	4.8	5.3	5.2	4.4	2.9	1.1	20.1
Ga	17.1	17.3	19.3	18.5	20.7	16.6	15.0	23.2	20.4
Zn	5.4	5.8	9.8	12.8	10.5	9.3	e.9	12 2	23.J 16 7
NI	2.3	2.6	9.6	3,2	2.0	16.7	1.3	13.2	17.6

# ANORTHOSITIC & LEUCOGABBROIC GNEISS

Name	DMSM4	DMSR16A	DMS-83B	DMS-66	DMS134B	DMSH9B	DMSP38	DMSP3G	DMSR12
S102	53.53	49.68	47.42	47.12	49.10	48.60	50.44	51.21	47.95
T102	0.16	0.57	0.29	1.46	0.29	0.55	0.95	0.95	2.05
A1203	29.40	22.97	22.74	18.72	25.00	25.86	19.40	25.01	13.25
Fe203	0.18	0.67	1.08	1.57	0.71	0.69	1.14	0.75	1.79
FeO	1.21	4.47	7.17	10.48	4.75	4,62	7.63	5.00	11.93
MnO	0.02	0.08	0.13	0.16	0.08	0.09	0.13	0.08	0.22
MgQ	0.56	4.10	6.10	6.38	4.93	3.32	4.52	1.70	5.88
CaO	11.72	13.35	11.39	9.29	10.54	10.46	12.30	11.63	10.40
Na20	4.48	3.33	3.09	3.14	3.45	3.15	3.26	3.70	3.56
K20	0.56	0.31	0.56	0.46	0.68	2.16	0.33	0.43	0.71
P205	0.03	0.03	0.04	0.28	0.15	0.07	0.08	0.15	0.23
Total	101.85	99.56	100.00	99.07	99.67	99.57	100.18	100.61	97.97
CIPW	Norms								
Cor	0.19								
Or	3.31	1.83	3.31	2.72	3.99	12.77	1.95	2.54	4.20
Ab	36.73	23.94	19.10	26.57	26.78	17.56	27.59	31.31	25.73
An	57.94	46.82	46.54	35.64	50.75	50.06	37.34	50.38	18.08
Ne	0.64	2.30	3.82		1.31	4.92			2.38
Di		15.69	7.97	7.13	0.46	1.13	19.19	5.34	26.64
Hy				2.07			2.06	5.24	
01	2.40	6.86	17.07	19.24	14.46	10.92	8.41	2.57	13.92
Mt	0.26	0.97	1.56	2.28	1.03	1.00	1.66	1.09	2.59
Ilm	0.30	1.08	0.55	2.77	0.55	1.04	1.80	1.80	3.89
Ap	0.07	0.07	0.09	0.65	0.35	0.16	0.19	0.35	0.53
Trace	elements	in ppm.							
Cr	13.0	270.2	99.2	67.0	79.5	39.1	57.6	13.5	98.4
V	20.9	136.8	62.2	157.9	51.7	83.7	233.9	174.8	393.6
Ba	92.9	80.2	89.3	534.4	92.2	250.8	171.1	105.5	165.4
La	1.4	1.6	0.2	11.7	2.6	2.5	4.0	4.5	5.8 20 E
Ce	1.8	0.1	0.9	23.4	5.0	14.5	8.1	7.8	10.5
Nd	2.4	2.0	2.6	14.4	2.7	8.0	7.4	7.0	13.3
Nb	1.1	0.6	1.6	2.2	1.0	2.5	2.3	1.8	110 7
Zr	0.1	4.8	21.9	35.5	5.6	22.1	25.4	40.0	42.1
Y	2.9	9.8	11.5	11.9	4.9	12.7	13.6	10.5	200 0
Sr	467.6	385.6	322.2	722.7	445.1	771.9	518.3	204.4	42 0
RЬ	6.0	4.9	7.1	30.5	11.2	65.5	5.2	5.8	0.31 6 3
Th	4.1	4.0	2.8	5.7	0.1	0.6	3.3	2.1	25 1
Ga	21.0	20.9	18.2	22.1	19.2	23.4	24.J 75 5	23.3 23.3	129.9
Zn	13.5	33.7	55.6	55.7	39.6	47.7	(3.3	10 0	50.7
Ni	9.4	40.7	305.0	19.9	74.6	42.7	51.3	(3.3	JU.1

# ASSOCIATED MAFIC & ULTRAMAFIC ROCKS

.

Name	DMS-570	: DMSK4	DMSD91	DMSH79	DMSR39A	DMSR39B	DMSH107A	DMSH107	B DMSH108
\$102	46.23	52.21	37.70	49.36	36.64	44.87	49.71	48.98	41.88
T102	1.19	1.01	4.95	0.47	0.13	0.26	1.33	1.34	4.33
A1203	16.12	15.97	16.68	9.93	2.50	5.88	16.82	18.66	12.62
Fe203	1.66	1.36	2,91	1.35	3.47	1.91	2.26	2.08	3.70
FeD	11.05	9.09	19.37	9.03	23.10	12.75	9.04	8.32	14.81
MnO	D.22	0.18	0.65	0.19	0.14	0.16	0.16	0.17	0.33
MaŪ	8.37	6.60	2.64	13.50	24.33	24.21	6.34	4.96	5.14
CaO	11.28	8.08	10.67	12.52	4.82	7.75	9.87	10.03	8.42
Na20	2.14	2.71	1.61	1.29	0.17	0.55	2.23	2.96	3.20
K2D	0.14	1.27	0.58	0.63	0.18	0.30	D.71	0.60	1.17
P205	0.19	0.11	0.88	0.10	0.03	0.05	0.38	0.50	1.92
Total	98.58	98.59	98.64	98.38	95.51	98.69	98.85	98.60	97.53
CIPW	Norms								
Qtz		0.79					1.39		
Or	0.83	7.51	3.43	3.72	1.06	1.77	1.33	1.34	4.33
Ab	18.11	22.93	11.32	10.92	0.42	4.65	18.87	25.05	25.42
An	33.97	27.67	36.58	19.45	5.53	12.69	33.80	35.87	16.52
Ne			1.25		0.55				0.36
Di	17.06	9.63	9.16	33.91	14.84	20.41	10.42	8.77	10.52
Hy	6.22	25.92		14.25		13.63	23.49	15.79	
01	17.30		21.26	13.05	67.77	42,15		2.85	18.55
Mt	2.40	1.98	4.21	1.96	5.02	2.77	3.28	3.02	0.00
Ilm	2.26	1.92	9.40	0.83	0.25	0.49	2.53	2.54	8.22
Ap	0.44	0.25	2.04	0.23	0.07	0.12	0.88	1.16	4.40
Traco	alamaata	in nom							
Tr.	307 2	20.0	38.9	599.1	763.6	1567.8	106.3	75.6	1.8
v	316 9	194.8	89.0	238.1	65.6	112.6	377.1	242.0	231.7
Ra	24 0	180.1	124.3	293.5	50.9	88.2	354.3	352.5	734.9
la la	1 9	17.4	13.6	4.1	0.1	0.1	17.1	21.1	44.2
C	7.0	41.3	31.0	27.6	8.1	3.8	36.8	46.5	86.4
Nd	7.3	21.5	23.0	14.5	0.7	2.5	23.3	33.2	76.3
Nb	4.0	6.0	24.8	2.6	1.4	1.2	6.8	9.2	12.3
Zr	63.4	145.5	42.7	33.6	10.1	16.8	41.4	25.7	386.0
Y	37.1	33.9	78.1	15.6	7.1	7.9	22.1	24.6	89.4
Sr	103.7	208.3	266.0	292.7	69.2	149.9	591.5	717.3	370.9
Rb	0.3	31.3	20.3	13.6	3.3	8.1	18.7	9.9	14.2
Th	2.7	7.9	6.8	0.1	3.7	1.8	1.6	0.1	0.1
Ga	18.8	18.3	23.9	10.2	7.2	7.4	22.3	23.3	26.8
Zn	60.9	93.2	209.5	83.3	154.3	99.9	131.9	131.0	213.0
Ni	117.0	54.7	7.5	38.8	2615.9	485.0	27.1	20.2	19.7

#### **APPENDIX III - Microprobe analyses**

Microprobe analsyses were obtained from carbon-coated, polished thin sections using both wavelength (WD) and energy (ED) dispersive techniques on a Cambridge Instruments Microscan V electron probe at the University of Leicester. An accelerating potential of 15 Kv was applied and a current of approximately 21 nano amps (nA) on Cu for WD, and 5 nA on Co for ED analyses. A range of natural and synthetic standards were used and ZAF and dead-time corrections applied using the program FRAME (Yakowitz ct al., 1974). Analyses were obtained from both focussed point sources and 50 x 50  $\mu m$  area scans; the latter applied to spinel-clouded plagiolcase, bulk symplectite and "dusty" primary clinopyroxene in metagabbros to estimate the contribution of the minor phase (spinel, clinopyroxene or amphibole and ilmenite respectitvely) to the host mineral. Several samples were also analysed using the CAMEBAX microbeam microprobe at the University of Kiel in West Germany where processing and corrections were made using both the PAP program, based on the model of Pouchou & Pichoir (1984), and a ZAF program available on the probe. These samples are preceded by K in the columns of microprobe analyses in Appendix I (e.g. KWD- etc.). Results from the PAP and ZAF corrections are compared in column 1 of Table AIII.1 and produce significant differences in the amounts of Fe, Al and Mg; the I change depending on the mineral being analysed.

In the tables of analyses which follow the mean and standard deviation for different phases within any one sample are listed in order of lithology and subdivided further in terms of subdomains; the sample numbers are given at the bottom of each set of analyses. WD analyses are quoted to 2 decimal places while ED are quoted to one. In WD analyses the machine precision is given by the standard deviation and depends on both the mineral being analysed and on the count rates. If the Std deviation is quoted as a percentage of Wt% oxide, it provides a minimum estimate of uncertainty in the mineral analyses presented here and representative results  $(\pm)$  for various phases are presented in columns 2-10 of Table AIII.1. It is stressed that these values represent the minimum uncertainty because they were obtained directly from counts and do not take into account operator error. Nonetheless they always lie well within the std deviations reported below for each average set of mineral analyses.

A-25

TABLE AIII.1: A comparison of the PAP and ZAF corrections available on the CAMEBAX probe at Keil (column 1), and the % Std deviation for each element from a range of minerals (columns 2-10).

	PAP → ZAF	OL	OPX	CPX	SYM	GT	SP-PL	Ti-AMP	ILM	BIOT
Si02	+0.4-3.3%	0.9%	0.8%	0.8%	0.8%	0.8%	0.8%	0.9%	-	1.0%
Ti02	+1.2%	-	-	7.9	25.0	-	-	1.9	0.5	1.5
A1203	+1.7-4.8%	-	3.8	2.2	1.1	1.0	0.9	1.2	-	1.1
FeO	-2.5-5.5%	0.8	1.0	1.6	0.9	1.0	2.8	1.4	0.7	1.3
MnO	-4.0%	12.5	11.5	23.1	6.5	5.7	-	33.3	13.3	-
Mgû	+3.4-5.2%	0.9	1.0	1.2	1.6	1.8	6.6	1.3	5.1	1.1
CaO	+0.5%	-	5.6	0.6	1.0	0.8	1.0	1.0	-	-
Na20	+1.0-3.8%	-		4.9	27.3	-	2.4	3.8	-	9.4
K20	+0.6%	-	-	-	-	-	3.8	4.4	-	1.4
Total	+0.5-1.7%									

MEAN & STD DEVIATION FOR PHASES FROM METAGABBROS

	1	2	3	4	5	6	7
	OL.	OPX	CPX	SYM	PLAG	ILN	BIOT
\$102	34.77 +- 0.69	51.24 +- 0.47	51.57 +- 0.94	42.00 +- 1.48	54.49 +- 1.26	-	37.0 +- 0.3
T102	0.03 +- 0.01	0.08 +- 0.04	0.15 +- 0.12	0.08 +- 0.07	0.12 +- 0.08	51.8 +- 0.3	4.8 +- 0.4
A1203	-	1.33 +- 0.09	3.07 +- 0.72	17.96 +- 2.51	27.94 +- 0.53	-	14.4 +- 0.2
Fe0	41.00 +- 0.81	22.85 +- 0.77	8.33 +- 0.74	23.39 +- 1.91	2.45 +- 0.70	47.7 +- 0.3	13.3 +- 1.5
MnQ	0.26 +- 0.03	0.21 +- 0.02	0.10 +- 0.03	0.65 +- 0.17	- +- 0.02	0.2 +- 0.6	•
MgD	24.46 +- 0.71	22.33 +- 0.61	13.09 +- 0.21	7.69 +- 0.99	0.67 +- 0.23	1.0 +- 0.4	15.3 +- D.4
CaO	0.03 +- 0.03	0.39 +- 0.07	21.37 +- 0.58	9.43 +- 1.40	7.97 +- 0.54	•	•
N=20	-	-	1.09 +- 0.35	0.17 +- 0.23	6.14 +- 0.23	0.3 +- 0.8	0.2 +- 0.7
K20	-	-	-	-	0.21 +- 0.09	-	9.4 +- 0.9
Total	100.55	98.43	98.77	101.37	99.99	101.1	94.5
Cation	•						
0	4.000	6.000	6.000	12.000	32.000	3.000	22.000
Si	0.989	1.947	1:942	3.196	9.894	-	5.545
TL	0.001	0.002	0.004	0.005	0.016	0.975	0.544
A1	-	0.060	0.136	1.611	5.980	-	2.536
Fe2	0.976	0.726	0.252	1.488	0.372	0.999	1.669
Mn	0.006 4	0.007	0.003	0.042	•	0.004	-
. Ng	1.037	1.265	0.735	0.872	0.181	0.039	3.422
Ca	0.001	0.016	0.862	0.769	1.551	-	-
Na	-	-	0.080	0.025	2.162	0.015	0.050
ĸ	-	-		• ·	0.049	-	1.796
Sum	3.010	4.021	4.025	8.007	20.205	2.032	15.570
Inter-e	lement ratios				•		
XFe		0.3606	0.1408				
XHg		0.6281	0.3945				
XCa		0.0079	0.4629				
XMn		0.0034	0.0017				
An	•				41.2		
Áb					57.5		
Or					1.3	•	
Mg No.	51.5	63.5	73.7	36.9	32.8	3.8	67.2
1 85	DHS-18, OLIVINE	2	050MS-18, 0PX	3	850MS-18, CPX		
4 85	DHS-19, GT SYN	5	850MS-18, SP-CL0	NUDED PLAG 6	850HS-19, ILM		
7 85	UNS-18, BIOT						

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MEAN & STO DEVIATION FOR PHASES FROM METAGABBROS

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	1	2	з	4	5	6	7	8
	AMPH	OLIV	0PX	CPX	AMPH	SYM	61	PLAG
\$102	40.7 +- 0.1	36.4	53.4 +- 0	.s 52.7 += 1.6	41.8 +- 1.4	41.90 +- 3.04	39.7 +- 1.1	54.06 +- 1.68
T102	3.2 +- 0.6	-	-	-	0.7 +- 0.2	0.06 +- 0.03	-	0.12 +- 0.05
A120	3 13.3 +- 0.7	-	1.2 +- 0	3.5 +- 1.2	14.7 +- 0.7	18.28 +- 4.25	21.7 +- 1.6	28.03 +- 0.92
FeQ	13.8 +- 0.1	35.7	20.5 +- 0	.6 7.0 +- 0.9	10.9 +- 0,4	21.98 +- 4.44	24.7 +- 1.6	1.95 +- 1.27
MnO	-	-	•	-	<b>-</b> '	0.51 +~ 0,18	0.7 +- 0.2	<b>-</b> ,
MgO	10.6 +- 0.1	28.9	23.9 +- 0	.8 13.8 +- 0.4	13.3 +- 0.4	9.68 +- 2.09	8.1 +- 0.5	0.70 +- 0.53
CaO	11.4 +- 0.4	-	-	21.6 +- 1.7	11.9 +- 0.3	8.56 +- 5.34	8.3 +- 1.5	8.23 +- 1.82
Na20	2.7 +- 0.3	•	-	1.2 +- 0.8	2.8 +- 0.5	-	-	8.27 +- 0.77
K20	1.4 +- 0.3	-	-	•	0.8 +- 0.3	-	-	0.14 +- 0.04
Total	97.1	101.0	99.0	99.8	97.0	100.97	101.2	99.50
Cati	90.0							
0	23.000	4.000	6.000	6.000	23.000	12.000	12.000	32.000
Si	6.123	0.999	1.983	1.948	6.179	3.170	3.018	9.856
TL	0.363	-	-	•	0.073	0.003	•	0.016
A1	2.352	-	0.052	0.153	2.566	1.630	1,946	6.024
F#2	1.732	0.819	0.636	0.215	1.346	1.391	1.568	0.297
Mn	-	-	-	-	-	0.033	0.043	•
Ng	2.391	1.182	1.320	0.759	2.937	1.092	0.921	0.190
Ca	1.848	-	-	0.857	1.886	0.694	0.511	1.608
Na	0.789	•	-	0.085	0.807	-	•	2.217
x	0.269	-	-	-	0.151	-	•	0.033
Sum	15.867	3.001	3.991	4.017	15.944	8.012	8.009	20.240
Inter	-element ratios							
XFe			0.3250	0.1177			0.5153	
XHg			0.6750	0.4144			0.3026	
XCa				0.4679			0.1680	
XHn							0.0142	
An								41.7
Ab								57.5
Or								0.8
Hg Na	. 58.0	59.1	67.5	77.9	68.6	44.0	37.0	0.00
1	85DMS-18, AMPH		2 850	HS-6, OLIVINE	3 8504	5-8, OPX		
4	850MS-6, CPX		5 850	MS-6, AMPH	6 85DH	IS-6, GT SYM		
7	850MS-6, GT		8 850	IMS-6, SP-CLOUDED PL/	NG			

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MEAN & STD DEVIATION FOR PHASES FROM METAGABBROS

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	1	2	3	4	5	6	7
	0L	OPX	CPX	SYN	GT	PLAG	PLAG
\$102	36.87 +- 0.17	53.55 ++ 0.35	52.55 +- 0.61	40.66 +- 2.31	38.88 +- 0.64	54.11 +- 1.35	58.3 +- 1.4
T102	•	0.04 +- 0.02	0.15 +- 0.09	0.16 +- 0.26	0.01 +- 0.03	0.12 +- 0.07	-
A1203	) _	1.87 +- 0.26	3.75 +- 0.95	20.39 +- 3.07	22.78 +- 0.70	28.43 +- 1.24	25.4 +- 0.8
Fe0	34.09 +- 1.44	19.45 +- 0.78	6.51 +- 0,62	21.11 +- 2.09	22.92 +- 1.05	2.10 +- 0.78	-
MnŰ	0.20 +- 0.06	0.22 +- 0.09	0.09 +- 0.01	0.63 +- 0.09	0.67 +- 0.09	-	-
MgQ	30.50 +- 1.20	24.51 +- 0.28	14.04 +- 0.68	9.73 +- 0.75	<b>0.</b> 94 +- 0.30	1.00 +- 0.34	+
CaO	0.01 +- 0.03	0.44 +- 0.44	21.57 +- 0.85	7.77 +- 2.12	6.47 +- 1.09	7.42 +- 0.30	7.4 +- 0.6
Na20		0.01 +- 0.03	1.19 +- 0.22	0.18 +- 0.23	-	6.21 +- 0.32	7.4 +- 0.4
K20	-	•	-	-	-	0.24 +- 0.07	0.3
Total	101.67	100.49	99.85	100.63	100.67	99.63	98.7
Catio	ans						
0	4.000	6.000	6.000	12.000	12.000	32.000	32.000
Si	0.997	1,953	1.938	3.072	2.952	9.836	10.550
Ti	-	0.001	0.004	0.009	0.001	0.016	
A1	-	0.080	0.163	1.816	2.039	6.092	5.418
F+2	0.771	0.593	0.201	1.334	1.455	0.319	-
Hn	0.005 /	0.007	0.003	0.040	0.043	-	-
Mg	1.230	1.354	0.772	1.096 .	1.012	0.271	-
Ca	-	0.017	0.852	0.629	0.526	1.445	1.444
Ha	• '	0.001	0.085	0.026	-	2.189	2.595
ĸ	-	-	-	-	-	0.056	0.052
Sum	3.003	4,006	4.019	8.024	8.028	20.224	20.070
Inter	-element ratios						
XFe		0.3009	0.1099	•	0.4793		
XHg		0.6869	0.4223		0.13332		
XCa		0.0087	0.4663		0,113		
XMn	·	0.0034	0.0015		0.0142	39.2	35.2
An						59.2	63.3
Ab						15	1.5
0#			<b>.</b>		41.0	45.9	
Mg Na	61.5	69.5	79.4	45.1	÷1.0		
1	85DMS-7, OLIVINE	. 2	850MS-7, 0PX	3	85DMS7, CPX		
4	850MS7, GT SYM	5	850MS-7, GT	6	85DMS-7, SP-CL	OVOED PLAG	
7	850MS-7, MOAT PLAG	i				,	

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MEAN & STO DEVIATION FOR PHASES FROM METAGABBROS

	•	2	3	4	5	6	7
	SPIN	TI M	BI	AMPH	0L,	OPX	CPX
\$102	0.2 += 0.4	1.1 - 1.8	36.8 +- 1.3	41.6 +- 2.5	<b>36.52 +- 0.53</b>	53.36 +- 0.71	53,12 +- 0.53
T102	-	51.9 +- 4.8	6.8 +- 0.4	3.6 +- 0.4	-	0.04 +- 0.01	0.13 += 0.08
A1203	- 61.9 += 0.8		15.6 +- 0.6	13.8 +- 2.8	-	1.67 +- 0.45	3.30 ++ 0.3+
Cr203	0.3 += 0.5	•	-	-	-	-	-
F.O	28.8 +- 1.1	45.3 +- 2.0	12.1 +- 0.8	10.4 +- 1.1	36.34 +- 1.79	20.85 +- 0.27	7.30 +- 0.33
Mn0	0.1 += 0.3	0.3 +- 0.7	-	-	0.18 +- 0.04	0.19 + 0.02	0.03 +- 0.08
Maû	11.2 ++ 1.0	2.7 +- 2.8	15.4 +- 0.9	12.2 +- 0.9	28.88 +- 1.56	24.21 +- 0.22	13.72 += 0.40
C.0	-	-	0.2 +- 0.9	12.2 +- 1.8	-	0.35 +- 0.87	21.61 +- 1.27
N=20	0.8 += 0.3	-	0.4 +- 0.7	2.7 +- 0.6	-	•	1.14 +- 0.35
K20	-	-	9.8 +- 0.5	1.3 +- 0.4	-	•	-
Total	101.3	101.3	97.2	97.9	101.92	100.67	100.41
Catio	<b>ne</b>						S-000
0	4.000	3.000	22.000	23.000	4,000		1.953
Si	0.006	0.028	5.352	6.117	0.996	1.333	0.004
TL	-	0.956	0.747	0.401	•	0.001	0.143
A1	1.943	-	2.667	2.387	-	0.072	•
Cr .	0.006	-	-	•	-	-	0.225
Fe2	0.596	0.928	1.472	1.283	0.829	0.006	0.003
Hn	0.002	0.005	-	•	0.004	1 777	0.752
Ng	0.443	0.099	3.338	2.670	1.174	0.014	0.851
Ca	•	•	0.026	1.924	•	0.014	0.081
Na	0.043	-	0.110	0.766	-	_	
ĸ	•	-	1.822	0.247	-	A.008	4.012
Sum	3.040	2.016	15.534	15.796	3.004	4.000	
Inter	-element ratios					0.3225	0.1226
XFØ						0.6675	0.4108
XMg						0.0069	0.4651
XCA						0.0030	0.0015
Ng Ne	. 42.7	9.6	69.4	67.5	58.6	\$7.4	77.0
1	850M5-7 681NM	•	950NC_7 114	1	BSOMS-7. BIOT		
i	ASDMS_7 TI_AMOU	2 2	850HS_8. 011V1	NF E	850HS-8, OPX		
7	BSOMS-8. CPX	3	43413-01 UC114				

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	1	2	3	4	5	6	7
	SYM	GT	PLAG	PLAG	OL	OPX	CPX
\$102	41.54 +- 2.73	39.58 +- 0.45	54.22 +- 1.47	58.9 +- 1.5	36.27 +- 0.45	53.57 +- 1.47	53.19 +- 0.96
T102	0.13 +- 0.16	0.02 + 0.09	0.13 +- 0.04	-	~	0.01 +- 0.03	0.04 +- 0.09
A1203	19.32 +- 3.90	21.95 +- 0.63	28.27 +- 0.84	25.2 +- 1.0	•	1.09 +- 0.52	3.26 +- 0.59
F+0	21.61 +- 3.83	23.53 +- 2.48	2.07 +- 0.77	-	38.98 +- 1.14	21.94 +- 1.20	7.48 +- 0.89
Nn0	0.56 +- 0.09	0.59 +- 0.08	-	-	-	0.26 +- 0.04	0.10 +- 0.02
MgQ	9.36 +- 0.96	8.42 +- 0.60	0.81 +- 0.29	-	26.07 +- 0.78	22.67 +- 1.07	13.70 +- 0.30
CaO	8.62 +- 3.33	6.77 +- 1.87	7.90 +- 0.59	6.7 +- 1.2	0.01 +- 0.03	0.67 +- 0.95	21.61 +- 1.19
Na20	0.25 +- 0.21	-	5.21 +- 0.24	7.6 +- 0.7	-	-	0.65 +- 1.27
K20		-	0.21 +- 0.04	0.3 +- 0.1	-	-	- +- 0.01
Total	101.39	100.86	99.82	98.B	101.33	100.21	100.03
Cation	•						
0	12.000	12.000	32.000	32.000	4.000	6.000	6.000
SL	3.127	3.006	9.848	10.635	1.007	1.982	1.961
TL	0.007	0.001	0.018	0.003	-	-	0.001
A1	1.714	1.965	6.052	5.367	-	0.048	0.142
F#2	1.360	1.495	0.314	-	0.905	0.679	0.231
Mn	0.036 ,	0.038	-	•	-	0.008	0.003
Нg	1.050	0.953	0.219	· -	1.079	1.250	0.753
Ca	0.695	0.551	1.538	1.304	`•	0.027	0.854
Na	0.036	-	2.187	2.661	-	-	0.046
ĸ	-	-	0.049	0.078	-	-	-
Sum	8.027	8.010	20.226	20.048	2.993	3.994	3.990
Inter-	element ratios			-		A 3/57	n 1953
XFe		0.4922				0.3437	0 4091
XHg		0.3139				0.0300	0 4639
XCa		0.1814				0.0133	0.0017
XMn		0.0125				0.0041	0.0011
An	•		40.7	32.3			
Аb			58.0	65.8			
0r	•		1.3	1.9		<b>.</b>	76 6
Mg No.	43.6	38.9	41.1		54.4	64.8	(0.0
1 8	SDMS-8, GT SYM	2	85DM <b>5-8, GT</b>	3	85DMS-8. SP-CL	OUDED PLAG	
4 8: 7 84	SOMS-8, CLEAR PLA 4DMS-13A, CPX	G 5	84DHS-13A, OLIV	INE G	840M5-13A, UPX	•	

MEAN & STO DEVIATION FOR PHASES FROM METAGABBROS

	•	•	2	▲	5	6	7
	AMDU	с сум	SYN	6T	CPX	PLAG	ILM
5102	42 01 a- 1 80	3171 1 41 41 41 1 00	40 44 4- 2 39	38.94 +- 0.59	51.30 +- 1.	73 59.45 +- 2.48	-
T102	0 41 - 0 47		0.07 += 0.06	0.04 +- 0.03	0.88 +- 1.	34 -	52.14 +- 0.32
A1203	14 99 4- 2 01		19 46 4- 3.80	21.78 +- 0.70	3.83 +- 1.	06 25.47 +- 1.84	-
C=203		10.23 ** 1.41		0.01 +- 0.04	-	-	-
F=0	11 69 4- 1 13		21 91 A- 4.58	25.03 +- 2.11	8.51 +- 0.	89 -	46.57 +- 0.07
Hol			0.74 += 0.22	0.87 +- 0.13	0.10 +- 0.	03 -	0.28 +- 0.04
Maß	13 36 4- 0 65		8 90 - 1 69	7.09 +- 1.03	12.91 +- 0.	90 -	0.97 +- 0.08
C-0	11 87 4- 0 70		8 17 4= 2 58	6.44 +- 1.09	21.39 +- 1.	67 7.15 +- 1.44	-
N-20	3 15 0		0 58 4- 0 69	-	0.93 +- 1.	05 7.26 +- 1.10	0.02 +- 0.07
120	J.11 - U.JU		0.14 += 0.00	-	-	0.18 +- 0.09	-
Tatal	0.63 += 0.13	0.03 +- 0.03	100 37	100.20	99.85	99.51	99.98
	31.14	33.07	(00.31				
Catior							43.000
0	23.000	12.000	12.000	12.000	6.000	32.000	12.000
Si	6.172	2.161	3.091	3.003	1.912	10.643	
TL	0.045	0.003	0.004	0.002	0.025	-	3.932
AL	2.594	1.652	1.753	1.980	0.168	5.375	• •
Cr	-	-	-	0.001	-	-	3 925
F+2	1.436	1.445	1,401	1.614	0.265	•	0.024
Mn	0.007	0.054	0.048	0.057	0.003	-	0.146
Hg	2.904	1,009	1.014	0.815	0.717	-	
Ca	1.821	0.671	0.666	0.532	0.854	1.3/4	0.004
Na	0.886	0.028	0.086	-	0.067	2.320	
κ	0.122	0.003	0.014	•	•	0.047	8.050
Sum	15.989	8.026	8.079	8.004	4.013	13.320	
Inter	-element ention						
XFe				0.5348	0.1442		
XHa				0.2700	0.3898		
XCa				0.1763	0.4643		
XHo				0.0186	0.0017		
An						34.9	
Ab						64.1	
Or						1.0	
Hg No	. 68.9	41.1	42.0	33.6	73.0		, 3.6
			840WE-101 07		84DHS-134.	AMPH-GT SYM	
i i	BADME-13A, PALE A	171771 <b>4</b>	ALONG_134, 014		84045-134.	CLEAR PLAG	
7	940-34134, UI 84045-134 11 Menu		G-GHJ-HAL PHI		21212 1211		
•	A A A A A A A A A A A A A A A A A A A	16					

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	+	,	3	4	5	6	7
	BI	AMPH	PLAG	DPX	CPX	SYM	GT
S102	36.13 +- 0.83	40.32 +- 0.47	54.00 +- 0.53	53.00 +- 0.68	52.86 +- 1.49	42.85 +- 1.80	38.84 ++ 0.37
T102	4.63 +- 1.53	2.54 +- 0.20	0.13 +- 0.03	- ·	0.11 +- 0.16	0.07 +- 0.07	0.05 +- 0.04
A1203	16.05 +- 1.11	15.67 +- 0.37	28.42 +- 0.56	1.27 +- 0.50	3.17 +- 0.82	16.80 +- 3.45	21.67 +- 0.30
Cr203	•	0.01 += 0.04	•	-	•	-	- +- 0.03
F+0	13.35 +- 2.02	12.81 +- 0.98	2.99 +- 0.55	23.29 +- 1.70	8.92 +- 1.28	21.40 +- 2.81	26.56 +- 1.44
MnD	0.01 +- 0.05	0.09 +- 0.03	-	0.23 +- 0.04	0.11 +- 0.05	0.55 +- 0.12	0.66 +- 0.14
Hoū	15.11 +- 1.95	10.94 +- 0.38	0.89 +- 0.33	22.07 +- 1.37	13.09 +- 0.73	8.74 +- 1.54	6.43 +- 0.88
CaO	0.02 +- 0.04	11.33 +- 0.15	7.24 +- 0.29	0.50 +- 0.11	20.80 +- 0.85	10.26 +- 2.82	6.39 +- 0.35
Na20	0.49 +- 0.26	3.08 +- 0.19	6.44 +- 0.12	-	1.20 +- 0.31	0.28 +- 0.17	•
K20	9.20 +- 0.40	0.91 +- 0.02	0.15 +- 0.03	-	- +- 0.01	0.08 +- 0.07	-
Total	94.99	97.70	100.26	100.36	100.26	101.03	100.60
Cation							
0	22.000	23.000	32.000	6.000	6.000	12.000	12.000
Si	5.383	5.984	9.798	1.971	1.950	3.250	3.002
Ti	0.519	0.283	0.018	-	0.003	0.004	0.003
Al	2.819	2.741	6,078	0.056	0.138	1.502	1.9/4
Cr	· -	0.001	-	-	-	-	-
F+2	1.663	1.590	0.454	0.724	0.276	1.357	1.717
Mo	0.001	0.011	-	0.007	0.003	0.035	0.043
Mg	3.356	2.420	0.241	1.223	0.723	0.988	0.741
Ca	0.003	1.802	1.408	0.020	0.825	0.834	0.529
Na	0.142	0.086	2.266	-	0.086	0.041	-
к	1.749	0.172	0.035 "	-	-	0.000	* *
Sum	15.634	15.891	20.296	4.001	4.013	6.020	8.004
Inter-	element ration						
XFe				0.3668	0.1512		0.3660
XHg				0.6195	0.3954		0.2443
XCa				0.0101	0.4516		0.1/40
XHn				0.0037	0.0019		0.0143
An			38.0				
Ab			61.1				
0r			0.9				1 06
Mg No.	66.9	60.4	34.7	62.8	72.3	42.1	34.7
1 8 4 8 7 8	40MS-13A, BIOT 40MS-19, OPX 40MS-19, GT	2 5	840MS-13A, TI-A 840MS-19, CPX	мрн 3 Б	840MS-13A, SP- 840MS-19, GT S	CLOUDED PLAG Ym	

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MEAN & STO DEVIATION FOR PHASES FROM METAGABBROS

		•	•	4	5	6	7
	1	2	LINDU	PLAG	PLAG	PLAG	QT
	104	81	ADEN 10 10 10 0 60	55.01 += 0.75	59.90 +- 1.60	57.6 +- 1.1	38.6 +- 1.0
3102	-	100 - 2 03	3 17 4- 0 27	0.13 +- 0.05	-	•	-
1102	51.11 +- 0.50	4,36 2.62	10.01 to 0.01	27 75 += 0.50	24.17 +- 0.91	26.5 +- 0.7	21.7 +- 0.5
A1203	0.02 += 0.03	13.24 += U.18	13.31 +- 0.80	-	-	-	•
LF203	0.03 +- 0.03	0.14 +- 0.24	12 05 4- 0.99	2.66 ++ 0.35	-	-	28.1 +- 1.0
reu	+6.88 +- U.58	13.20 +- 2.14			-	-	1.1 +- 0.2
HnU HnU	0.19 + 0.04	- +- 0.02	0.02 +- 0.04	0 64 4- 0.23	-	-	S.1 +- 0.9
rigu	0.90 +- 0,35	14.00 +- 2.24	10.42 +- 0.66	7 65 0.17	6.44 += 1.11	8.7 +- 0.7	5.4 +- 0.4
UaU N- 20	-	0.01 +- 0.02	11.35 += 0.05	6 48 an 0.17	7.74 +- 0.79	6.5 +- 0.5	-
Mazu	•	0.34 ++ 0.06	2.62 += 0.13	0.25 += 0.06	0.28 +- 0.16	0.1 +- 0.2	-
K20	-	9.63 +- 0.31	1.37 ++ 0.10	100 59	98.53	99.3	101.1
Total	99.79	94.79	97.08	100.33			
Catio	7.6						
0	12.000	22.000	23.000	32.000	32.000	32.000	12.000
Si		5.436	6.048	9.941	10.822	10.371	2.987
Ti	3.934	0.558	0.359	0.018	•	-	-
AL	0.002	2.689	2.471	5.909	5.147	5.630	1,364
Cr	0.007	0.017	0.024	-	-	-	-
Fe2	3.966	1.663	1.746	0.402	-	-	1,444
Mn	0.016	-	0.003	•	-	-	0.074
Ma	0.136	3.321	2.341	0.172	-	•	0.108
C.	-	0.002	1.839	1.481	1.247	1,575	U.447
Na	•	0.099	0.756	2.270	2.712	2.266	•
x	-	1,839	0.263	0.058	0.065	0.011	
Sum	8.061	15.622	15.960	20.250	19.992	19.953	8.021
*	•						
YEA	-element fitios						0.5972
YMa							0.2319
YC							0.1466
YMe							0.0243
4.0				28.9	31.0	42.4 ·	
A.5				59.6	67.4	57.0	
0.				1.5	1.8	0.3	
Ha Na	. 3.3	66.6	57.3	30.0	•••		28.0
•							
1 .	84DHS-19, ILMENITE	2	840MS-19, BIOT	3	840MS-19, TI-A	MPH	
4	840HS-19, SP-CLOUD	EO PLAG 5	840HS-19, CLEAR	PLAG S	840HSA-2A, REX	IT PLAG	
7	840MSA-2A, GT		A-30	)			

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	1	2	3	1	4	5	6	7
	0P	X BIO	r af	IPH I	OL I	OPX	CPX	CPX
\$10	2 51.4 +	- 0.9 37.1 +-	0.6 41.1 4	- 1.2 33.65	+- 0.22 51.61	+- 0.44 51.6	4 +- 0.51 51.80	+- 0.44
T10	2 -	4.4 +-	0.9 1.8 +	- 0.6 0.02	+- 0.03 0.09	+- 0.02 0.2	7 +- 0.03 0.31	+~ 0.13
A12	03 2.1 +	- 0.6 15.1 +-	0.7 13.6 +	- 0.8 -	1.41	+- 0.25 3.0	9 +- 0.16 2.54	+- 0.25
Fe0	26.0 +	- 0.8 15.0 +-	2.7 15.1 +	- 0.9 47.71	+- 0.07 26.60	+- 0.99 11.20	3 +- 1.06 11.18	+~ 0.81
MnQ	0.2 +	- 0.3 -	-	0.45	+- 0.04 0.35	+- 0.02 0.1	9 +- 0.01 0.20	+- 0.04
MgO	19.8 +	- 0.6 14.8 +-	1.9 10.6 +	- 0.7 18.47	+- 0.63 19.05	+- 0.59 11.64	+- 0.27 12.24	+~ 0.67
CaO	0.3 +	- 0.1 -	11.4 •	- 0.4 0.02	+- 0.03 0.57	+- 0.12 21.0	5 +- 0.54 20.49	+~ 2.16
Na20	1 -	0.1 +-	0.4 2.3 +	- 0.3 -	0.01	+- 0.04 0.95	i +- 0.27 0.89	+- 0.09
K20	-	9.7 +-	0.1 1.2 +	- 0.3 -	-	-	-	
Tota	1 99.0	96.1	97.1	100.32	99.69	100.11	99.65	
Cati	ons							
0	6.000	22.000	23.000	4.000	6.000	6.000	5.000	
Si	1.948	5.500	6.189	0.996	1.967	1.942	1.953	
Ti	-	0.489	0.209	-	0.003	0.008	0.009	
A1	0.094	2.635	2.413	-	0.063	0,137	0.113	
Fe2	0.825	1.867	1.909	1.181	0.848	0.355	0.353	
Mn	4 0.008	-	• .	0.011	0.011	0.006	0.006	
Mg	1.116	3.270	2.386	0.815	1.082	0,652	0.688	
Ca	0.013	-	1.838	0.001	0.023	Q.848	0.828	
Na	-	0.029	0.666	-	0.001	0.069	0.065	
ĸ	-	1.837	0.238	-	-	-	-	
Sum	4.005	15.626	15.848	3.004	3.999	4.017	4.014	
Inte	r-element rat	ics						
XFe	0.4207				0.4315	0.1906	0.1881	
XHg	0.5690				0.5509	0.3505	0.3670	
XCa	0.0064				0.0118	0.4556	0.4416	
XHn	0.0039				0,0058	0.0033	0.0034	
Mg No	s. \$7.5	63.7	55.6	40.8	56.1	64.8	66.1	
1	840MSA-2A		2 840MSA-2A	, BIOT	3 84DHSA	-2A, TI-AMPH		
4	850MSA-89, 0	LIVINE	5 850MSA-88	, OPX	6 850MSA-	-88, CPX		
7	850MSA-88, P	RIM CPX						
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MEAN & STD DEVIATION FOR PHASES FROM METAGABBROS

	•	,	2	4	5	6	7
	57M	6T	PLAG	MAG	AMPH	SPIN	PLAG
\$102	40 21 4 2 26	20 50 - 0 22	56 27 en 1.10	0.4 +- 0.2	39.9 +- 0	.3 0.2 +- 0.6	59.5 +- 1.0
T102		0.03	0.11 - 0.11	3.5 +- 5.3	3.6 +- 0	.5 0.1 +- 0.2	-
A1202		0.03 01.66 to 0.64	27 02 4- 0 58	3.1 +- 6.8	13.1 +- 0	.3 54.0 +- 0.9	25.0 +- 1.1
6.203	· · · · · · · · · · · · · · · · · · ·	21.44 4- 0.41	-	0.5 +- 0.2	•	-	•
Fell	25 59 4- 2 09	27 95 44 1 19	1.15 ++ 0.70	87.0 +-11.4	16.8 +- 0	.7 39.9 +- 1.8	0.2 +- 0.6
NoD	1 03 4- 0 27	1 09 4= 0 16	-		•	-	•
Hall	5 40 A- 1 41	5 36 4- 0.57	0.16 +- 0.14	0.3 +- 0.7	9.0 +- 0	.3 4.9 +- 0.6	-
C.a.D	9 29 4. 2 05	6 20 cm 0 29	8 76 += 0.31	•	11.1 +- 0	.2 -	7.3 +- 0.7
Na20	0.20 += 3.03	0.50 - 0.25	6.52 += 0.22	-	2.6 +- 0	.3 0.8 +- 0.3	6.9 +- 0.1
K20	-		0.38 += 0.11	-	1.6 +- 0.	.2 -	0.3 +- 0.1
Total	101.04	100.73	100.06	94.8	97.8	99.9	99.2
Catio	na						
0	12.000	12.000	32.000	4,000	23.000	4,000	32.000
Si	3,110	3.003	10.156	0.018	6.058	0.005	10.688
Ti	0.002	0.002	0.015	0.125	0.409	0.002	
A1	1.753	1.968	5.748	0.171	2.355	1,853	3.298
Cr	-	-	-	0.019	-	-	-
FeZ	1.651	1.820	0.175	3.410	2.138	0.972	0.030
Hn	0.067	0.072	•	-	-	-	-
Mg	0.736	0.622	0.043	0.020	2.045	0,213	-
Ca	0.684	0.526	1.617	-	1.812	-	1.397
Na	0.016	•	2.317	-	0.766	0.045	2.423
ĸ	-	-	0.083	-	0.310	-	0.080
Sum	8.020	8.012	20.154	3,762	15.893	2.089	19.915
Inter	-element ratios						
XFe		0.5988					
XMg		0.2047					
XCa		0.1729					
XMn		0.0237					25.8
An			40.3				53.0
٨b			57.7				3.1
Or			2.1			17.9	6.1
Mg No.	. 30.8	25.5	19.7	0.6	48.3	1144	
1 1	BSDMSA-88. GT SYN	2	850MSA-88, GT	3	850HSA-88.	SP-CLOUDED PLAG	
4	BSDMSA-BB. MAGNETI	TE S	BSDMSA-88, TI-A	HPH 6	\$50KSA-68,	SPINEL '	
7 (	BSDHSA-88, PLAG AD	J GT					

	1	2	3	4	5	6	7
	OPX	CPX	CPX	PLAG	AMPH	01_	OPX
\$102	51.35 +- 0.40	52.30 +- 0.79	52.16 +- 0.28	62.4 +- 0.8	41.0 +- 0.8	32.7 +- 0.7	50.8 +- 1.9
T102	0.09 +- 0.05	0.13 +- 0.06	0.17 +- 0.01	- · ·	2.3 +- 0.6	-	0.1 +- 0.3
A1203	0.73 +- 0.09	1.56 +- 0.25	1.79 +- 0.44	23.1 +- 0.7	11.4 +- 0.7	-	0.9 +- 0.6
FeQ	29.63 +- 1.05	11.82 +- 1.21	12.47 +- 0.90	-	19.0 +- 0.9	54.7 +- 0.8	31.4 +- 1.1
MnO	0.94 +- 0.06	0.39 +- 0.03	0.40 +- 0.06	-	0.1 +- 0.3	0.6 +- 0.2	0.5 +- 0.1
MgO	16.90 +- 0.72	11.59 +- 0.56	11.27 +- 0.58	-	8.6 +- 0.1	13.4 +- 0.6	16.3 +- 1.1
CaO	0.55 +- 0.11	21.82 +- 0.63	21.31 +- 0.62	4.9 +- 0.2	11.5 +- 0.7	-	0.5 +- 0.2
Na20	•	0.72 +- 0.13	0.76 +- 0.21	8.4 +- 0.3	1.8 +- 0.4	-	0.1 +- 0.4
K20	•	-	-	0.4 +- 0.1	1.9 +- 0.2	-	-
Total	100.19	100.33	100.33	99.2	97.6	101.5	100.5
Catio	na						
0	6.000	6.000	6,000	32.000	23.000	4.000	6.000
SI	1.982	1.972	1,970	11.135	6.302	0.993	1.967
Ti	0.003	0.004	0.005	-	0.264	-	0.002
A1	0.033	0.069	0.080	4.868	2.066	-	0.043
F+2	0.956	0.373	0.394	-	2.446	1.391	1.017
Ma	,0.031	0.012	0.013	-	0.010	0.016	0.018
Mg	0.972	0.651	0.634	•	1.959	0.608	0.939
Ca	0.023	0.882	0.862	0.933 `	1.899	-	0.021
Na	-	0.053	0.056	2.909	0.537	-	0,008
ĸ	-	-	-	0.082	0.373	•	-
Sum	3.999	4.016	4.013	19.927	15.856	3.007	4.014
Inter	-element ratios		-				
XFe	0.4825	0.1943	0.2069				0.3098
XMg	0.4905	0.3396	0.3333				0.4103
XCa	0.0115	0.4596	0.4530				0.0104
XMn	0.0155	0.0065	0.0067				0.0033
An	•			23.8			
АЪ				74.1			
Or í				2.1			(0.0
Hg No.	. 50.4	63.6	61.7		44.5	30.4	48.U
1 6	40MSA-98, OPX	<sup>'</sup> 2	840HSA-9A, CPX	3	840MSA-9A, PRI	H CPX	
4 1	340MSA-9A, REXT PL	AG 5	840MSA-9A, RET	AMPH 6	850MSA+11A, OL	TATUE	

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7 850MSA-11A, 0PX

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MEAN & STO DEVIATION FOR PHASES FROM METAGABBROS

		_	•		5	6	7
	1	2	3	PH 10	PLAG	0L	OPX
	CPX	GT	CPX	60 A An 3.3	56.28 +- 1.04	32.92 +- 1.30	50.20 +- 1.30
\$102	51.1 +- 1.0	38.3 +- 0.5	51.2 +- 1.U	BU.4 T- 3.5	0.08 +- 0.10	•	-
T102	0.3 +- 0.3	-	0.4 +- 0.7	-	26.97 +- 0.58	- +- 0.03	1.07 +- 0.19
A120	3 2.7 +- 0.6	21.4 +- 0.7	2.6 +- 0.8	24,4 +- ++4	-	-	-
C+20	] -	-	0.1 += 0.3	0 1 4- 0 3	1.27 ++ 0.65	54.27 +- 1.28	31.38 +- 0.99
F+Q	14.4 +- 3.2	28.5 +- 0.4	14.1 +- 2.3	U.) V- U.J	-	0.61 +- 0.10	0.48 +- 0.10
MnO	0.3 +- 0.4	1.5 + 0.2	0.3	-	0.12 +- 0.08	12.76 +- 0.82	16.06 +- 0.77
MgQ	10.7 +- 0.7	4.8 +- 0.4	10.5 +- 0.6	- 	7.91 ++ 0.17	0.02 ++ 0.02	0.55 +- 0.19
CaO	19.5 +- 2.8	6.5 +- 0.3	19.7 +- 2.1	6.4 - 2.4	6 37 4- 0 26	-	•
Na20	1.2 +- 0.5	-	1.2 +- 0.6	7.7 +- 1.4	0.31 +- 0.24	-	-
K20	•	-	-	0.4 += 0.1	0.28 +- 0.08	100 58	99.74
Tota	1 100.2	100.9	100.1	99.2	33.20	100.50	
Cati	ens			•		1 000	e.000
0	6.000	12.000	6.000	32.000	32.000	4,000	4.000
Si	1.945	2.994	1.948	10.836	10.207	1.007	1.364
TL	0.007	-	0.011	•	0.011	•	
Al	0.120	1,968	0.118	5.163	5,766	-	0.043
Cr	•	-	0.003	-	-	•	
Fe2	0.459	1.863	0.450	0.015	0.193	1,300	1.026
Mo	0.011	0.099	0.010	-	•	0.018	0.016
Ma	P03-0	0.556	0.594	-	0.032	0.582	0.336
C.	0.794	0.542	0.802	1.183	1.537	0.001	0.023
Na	0.089	•	0.091	2.680	2.240	-	-
x	-	-	-	0.089	0.065	•	-
Sum	4.032	8.022	4.026	19.967	20.051	2.993	4.013
Inte							
XFa	0 2451	6 6069	0.2424				0.5128
XHa	0.2751	0.0000 A 1010	0 1201				0.4678
XC.	0.3231	0.1771	0.4323	•			0.0115
YHe	0.7671	0.0005	0.0052				0.0079
An I	0.0031	0.0313		29.9	40.0		
Ab				67.8	58.3		
0e				2.3	1.7		
MaN		33.0	52.9		14.4	29.5	47.7
1 <b>1</b> 1	4. 31.U	2J.U	20.3				
1	850HSA-11A, CPX	2	850MSA-11A, 6	r i	3 850HSA-11A. P	RIN CPX	
4	850MSA-11A, PLAG	MOAT S	850MSA-11A, S	P-CLOUDED PLAG	6 840MSA-11F, 0	LIVINE	
7	B4DHSA-11F, OPX						

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SYN +- 3.52 62. +- 0.03 2. +- 6.04 23. - +- 0.36 - +- 0.36 - +- 0.34 - +- 2.96 6. +- 1.57 5. 99.5 99.5 99.5 11.1	PLAG           09 +- 1.21           +- 0.01           01 +- 0.75           36 +- 0.91           04 +- 0.54           50 +- 0.16           99           100           117           -	GT 39.69 +- 0.46 0.05 +- 0.06 21.18 +- 0.26 - 28.60 +- 0.76 1.43 +- 0.14 4.55 +- 0.35 6.53 +- 0.28 - 101.03 12.000 3.018 0.003 1.948 - 1.866 0.095 0.523 0.523	HAG 1.36 +- 1.48 1.26 +- 1.15 0.26 +- 0.08 89.85 +- 6.57 0.01 +- 0.04 0.06 +- 0.08 - - 91.80 4.000 - 0.052 0.075 0.010 3.763 - 0.005	ILH 51.12 0.11 47.45 0.38 0.42 - - - - - - - - - - - - - - - - - - -	$\begin{array}{r} \text{BIOT} \\ 35.40 \leftarrow 0.98 \\ 6.38 \leftarrow 1.98 \\ 13.81 \leftarrow 1.28 \\ \hline \\ 21.34 \leftarrow 0.05 \\ 9.05 \leftarrow 1.62 \\ 0.02 \leftarrow 0.08 \\ 0.15 \leftarrow 0.15 \\ 9.43 \leftarrow 0.54 \\ 95.62 \\ \hline \\ 22.000 \\ 5.470 \\ 0.741 \\ 2.515 \\ \hline \\ 2.758 \\ 0.005 \\ 2.005 \\ \hline \\ 2.055 \\ \hline \\ 2.055 \\ \hline \\ 0.55 \\ \hline \hline \\ 0.55 \\ \hline 0.55 \\ \hline \\ 0.55 \\ \hline 0.55 \\ \hline \\ 0.55 \\ \hline 0$	AHPH 40.34 +- 0.84 3.30 +- 0.91 12.38 +- 1.16 - +- 0.03 18.76 +- 1.09 0.13 +- 0.04 7.98 +- 1.02 10.93 +- 0.29 2.36 +- 0.33 1.75 +- 0.28 97.93 23.000 6.171 0.380 2.202 - 2.400 0.017 + 202	PLAG 56.66 ← 1.6 0.12 ← 0.0 27.27 ← 1.2 - 1.29 ← 1.0 - 0.13 ← 0.1 6.12 ← 0.1 0.37 ← 0.2 100.03 32.000 10.197 0.016 5.785 - 0.194 - 0.35
+- 3.52 62. +- 0.03 - +- 6.04 23. +- 0.36 - +- 0.34 - +- 2.96 - +- 1.57 5. +- 0.08 6. 0. 98. 98. 32.0	$00 \leftarrow 1.21 \\ +- 0.01 \\ 01 \leftarrow 0.75 \\ 04 \leftarrow 0.54 \\ 50 \leftarrow 0.54 \\ 50 \leftarrow 0.15 \\ 99 \\ 000 \\ 117 \\ - \\ 357 \\ - \\ - \\ - \\ - \\ - \\ - \\ - \\ - \\ - \\ $	38.69 +- 0.46 0.05 +- 0.06 21.18 +- 0.26 - 28.60 +- 0.76 1.43 +- 0.14 4.55 +- 0.35 6.53 +- 0.28 - 101.03 12.000 3.018 0.003 1.948 - 1.866 0.095 0.523 0.523	1.36 +- 1.48 1.26 +- 1.15 0.25 +- 0.08 88.85 +- 6.57 0.01 +- 0.04 0.06 +- 0.08 - - 91.80 4.000 - 0.052 0.075 0.010 3.763 - 0.005	- 51.12 0.11 - 47.45 0.38 0.42 - - 99.48 3.000 0.003 - 1.011 0.000 0.015	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$\begin{array}{rcrcrcccccccccccccccccccccccccccccccc$
+- 0.03 - +- 6.04 23. - +- 0.36 - +- 0.34 - +- 2.96 - +- 1.57 5. +- 0.08 8. 0.1 98.9 98.9	+- 0.01 01 $+-$ 0.75 04 $+-$ 0.91 04 $+-$ 0.54 50 $+-$ 0.15 99 100  - - - - - - - - - - - - -	$0.05 \leftarrow 0.06$ $21.18 \leftarrow 0.26$ $28.60 \leftarrow 0.76$ $1.43 \leftarrow 0.14$ $4.55 \leftarrow 0.35$ $6.53 \leftarrow 0.28$ - 101.03 12.000 3.018 0.003 1.948 - 1.866 0.095 0.523 0.523	1.36 +- 1.48 1.26 +- 1.15 0.26 +- 0.08 88.85 +- 6.57 0.01 +- 0.04 0.06 +- 0.08 - - - - - - - - - - - - -	51.12 0.11 	$6.38 \leftrightarrow 1.98$ $13.81 \leftarrow 1.28$ -2 $21.34 \leftrightarrow 1.37$ $0.04 \leftarrow 0.05$ $9.05 \leftarrow 1.62$ $0.02 \leftarrow 0.08$ $0.15 \leftarrow 0.15$ $9.43 \leftarrow 0.54$ 95.62 22.000 5.470 0.741 2.515 -2.758 0.005 2.005	3.30 +- 0.91 12.38 +- 1.16 - +- 0.03 18.76 +- 1.09 0.13 +- 0.04 7.98 +- 1.02 10.93 +- 0.29 2.36 +- 0.33 1.75 +- 0.28 97.93 23.000 6.171 0.360 2.232 - 2.400 0.017 + 200	$\begin{array}{c} 0.12 \leftarrow 0.0\\ 27.27 \leftarrow 1.2\\ \hline \\ 1.29 \leftarrow 1.0\\ \hline \\ 0.13 \leftarrow 0.1\\ 8.07 \leftarrow 0.2\\ 6.12 \leftarrow 0.1\\ 0.37 \leftarrow 0.2\\ 100.03\\ \hline \\ 22.000\\ 10.197\\ 0.016\\ 5.785\\ \hline \\ 0.194\\ \hline \\ 0.35\\ \end{array}$
+- 6.04 23. - +- 0.36 - +- 0.34 - +- 2.96 - +- 1.57 5.3 +- 0.08 8.1 0.3 99.3 32.0 11.1 - - - - - - - - - - - - -	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	21.18 +- 0.26 28.60 +- 0.76 1.43 +- 0.14 4.55 +- 0.28 - 101.03 12.000 3.018 0.003 1.948 - 1.866 0.095 0.523 0.523	1.26 +- 1.15 0.26 +- 0.08 88.85 +- 6.57 0.01 +- 0.04 0.06 +- 0.08 - - - 91.80 4.000 - 0.052 0.075 0.010 3.763 - 0.005	0.11 	$13.81 \leftarrow 1.28$ $-$ $21.34 \leftarrow 1.37$ $0.04 \leftarrow 0.05$ $9.05 \leftarrow 1.62$ $0.02 \leftarrow 0.08$ $0.15 \leftarrow 0.15$ $9.43 \leftarrow 0.54$ $95.62$ $22.000$ $5.470$ $0.741$ $2.515$ $-$ $2.758$ $0.005$ $2.085$	$12.38 \leftarrow 1.16$ - $\leftarrow 0.03$ $18.76 \leftarrow 1.09$ $0.13 \leftarrow 0.04$ $7.98 \leftarrow 1.02$ $10.93 \leftarrow 0.29$ $2.36 \leftarrow 0.33$ $1.75 \leftarrow 0.28$ $97.93$ $23.000$ $6.171$ $0.380$ $2.232$ - $2.400$ $0.017$	$27.27 \leftrightarrow 1.2$ $1.29 \leftarrow 1.0$ $0.13 \leftarrow 0.1;$ $8.07 \leftarrow 0.2;$ $6.12 \leftarrow 0.1;$ $0.37 \leftarrow 0.2;$ $100.03$ $32.000$ $10.197$ $0.016$ $5.785$ $0.194$ $0.05$
+- 0.36 - +- 0.34 - +- 2.96 - +- 1.57 5.: +- 0.08 8. 0.: 99.5 32.0 11.1	06 +- 0.91 06 +- 0.54 50 +- 0.16 99 1000 117 557 	28.60 +- 0.76 1.43 +- 0.14 4.55 +- 0.35 6.53 +- 0.28 - 101.03 12.000 3.018 0.003 1.948 - 1.866 0.095 0.523 0.523	0.26 +- 0.08 88.85 +- 6.57 0.01 +- 0.04 0.06 +- 0.08 - - 91.80 4.000 - 0.052 0.075 0.010 3.763 - 0.005	- 47.45 0.38 0.42 - - - - - - - - - - - - - - - - - - -	$21.34 \leftrightarrow 1.37$ $0.04 \leftarrow 0.05$ $9.05 \leftarrow 1.62$ $0.02 \leftarrow 0.08$ $0.15 \leftarrow 0.15$ $9.43 \leftarrow 0.54$ $95.62$ $22.000$ $5.470$ $0.741$ $2.515$ $-$ $2.758$ $0.005$ $2.085$	- +- 0.03 18.76 +- 1.09 0.13 +- 0.04 7.98 +- 1.02 10.93 +- 0.29 2.36 +- 0.33 1.75 +- 0.28 97.93 23.000 6.171 0.380 2.322 - 2.400 0.017 + 202	$1.29 \leftarrow 1.0$ $-$ $0.13 \leftarrow 0.1;$ $8.07 \leftarrow 0.2;$ $5.12 \leftarrow 0.1;$ $0.37 \leftarrow 0.2;$ $100.03$ $32.000$ $10.197$ $0.016$ $5.785$ $-$ $0.194$ $-$ $0.05$
+- 0.36 +- 0.34 2.96 1.57 5.3 +- 0.08 6.1 0.3 99.3 32.0 11.1	36 +- 0.91 04 +- 0.54 50 +- 0.16 99 100 117 - 557 - - - - - - - - - - - - -	28.60 + 0.76 $1.43 + 0.14$ $4.55 + 0.35$ $6.53 + 0.28$ $-$ $101.03$ $12.000$ $3.018$ $0.003$ $1.948$ $-$ $1.866$ $0.095$ $0.523$ $0.523$	88.85 +- 6.57 0.01 +- 0.04 0.06 +- 0.08 - - 91.80 4.000 - 0.052 0.075 0.010 3.763 - 0.005	47.45 0.38 0.42 - - 99.48 3.000 0.003 - 1.011 0.008 0.015	$21.34 \leftrightarrow 1.37$ $0.04 \leftarrow 0.05$ $9.05 \leftrightarrow 1.62$ $0.02 \leftarrow 0.08$ $0.15 \leftarrow 0.15$ $9.43 \leftarrow 0.54$ $95.62$ $22.000$ $5.470$ $0.741$ $2.515$ $-$ $2.758$ $0.005$ $2.005$	$18.76 \leftarrow 1.09$ $0.13 \leftarrow 0.04$ $7.98 \leftarrow 1.02$ $10.93 \leftarrow 0.29$ $2.36 \leftarrow 0.33$ $1.75 \leftarrow 0.28$ $97.93$ $23.000$ $6.171$ $0.380$ $2.232$ $-$ $2.400$ $0.017$	$1.29 \leftarrow 1.0$ $-$ $0.13 \leftarrow 0.1$ $8.07 \leftarrow 0.2$ $6.12 \leftarrow 0.1$ $0.37 \leftarrow 0.2$ $100.03$ $32.000$ $10.197$ $0.016$ $5.785$ $-$ $0.194$ $-$ $0.05$
+- 0.34 +- 2.95 1.57 5.3 +- 0.08 8.1 0.3 98.3 98.3 	06 ↔ 0.91 04 ↔ 0.54 50 ↔ 0.15 99 000 117 - 557 -	1.43 +- 0.14 4.55 +- 0.35 6.53 +- 0.28 - 101.03 12.000 3.018 0.003 1.948 - 1.866 0.095 0.523 0.523	0.01 +- 0.04 0.06 +- 0.08 - - 91.80 4.000 - 0.052 0.075 0.010 3.763 - 0.005	0.38 0.42 - - 99.48 3.000 0.003 - 1.011 0.008 0.015	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{c} - \\ 0.13 \leftarrow 0.1 \\ 8.07 \leftarrow 0.2 \\ 6.12 \leftarrow 0.1 \\ 0.37 \leftarrow 0.2 \\ 100.03 \\ \hline \end{array}$
+- 2.96 +- 1.57 5.3 +- 0.08 8.1 0.3 98.3 32.0 11.1 - - -	36 +- 0.91 04 +- 0.54 50 +- 0.15 39 100 117 557 - 	4.55 +- 0.35 6.53 +- 0.28 - - 101.03 12.000 3.016 0.003 1.948 - 1.866 0.095 0.523 2.512	0.06 +- 0.08 - - 91.80 4.000 - 0.052 0.075 0.010 3.763 - - 0.005	0.42 - - 99.48 3.000 0.980 0.003 - 1.011 0.008 0.015	$9.05 \leftrightarrow 1.62$ $0.02 \leftarrow 0.08$ $0.15 \leftrightarrow 0.15$ $9.43 \leftarrow 0.54$ 95.62 22.000 5.470 0.741 2.515 - 2.758 0.005 2.005	7.98 $\leftarrow$ 1.02 10.93 $\leftarrow$ 0.29 2.36 $\leftarrow$ 0.33 1.75 $\leftarrow$ 0.28 97.93 23.000 6.171 0.360 2.222 - 2.400 0.017 1.920	$\begin{array}{r} 0.13 \leftarrow 0.13 \\ 8.07 \leftarrow 0.23 \\ 6.12 \leftarrow 0.13 \\ 0.37 \leftarrow 0.23 \\ 100.03 \end{array}$
+- 1.57 5.3 +- 0.08 8.4 03 98.5 32.0 11.1 - - - -	36 ↔ 0.91 04 ↔ 0.54 50 ↔ 0.15 99 100  557	6.53 +- 0.28 - 101.03 12.000 3.016 0.003 1.948 - 1.866 0.095 0.529 0.529	- 91.80 4.000 - 0.052 0.075 0.010 3.763 -	- - - - 0.980 0.980 0.003 - 1.011 0.008 0.015	0.02 ← 0.08 0.15 ← 0.15 9.43 ← 0.54 95.62 22.000 5.470 0.741 2.515 - 2.758 0.005 2.005	10.93 ↔ 0.29 2.36 ↔ 0.33 1.75 ↔ 0.28 97.93 23.000 6.171 0.360 2.232 - 2.400 0.017 + 202	8.07 +- 0.2 6.12 +- 0.1 0.37 +- 0.2 100.03 32.000 10.197 0.018 5.785 - 0.194 - 0.35
+- 0.08 8. 0.5 99.5 32.0 11.1 - - - -	04 ↔ 0.54 50 ↔ 0.16 99 1000 117 557  	101.03 12.000 3.018 0.003 1.948 - 1.866 0.095 0.523	91.80 4.000 0.052 0.075 0.010 3.763 9.005	- 99.49 3.000 0.980 0.003 - 1.011 0.008 0.015	0.15 ↔ 0.15 9.43 ↔ 0.54 95.62 22.000 5.470 0.741 2.515 - - 2.758 0.005 2.085	2.36 +- 0.33 1.75 +- 0.28 97.93 23.000 6.171 0.380 2.232 - 2.400 0.017 + 220	6.12 +- 0.1 0.37 +- 0.2 100.03 32.000 10.197 0.016 5.785 - 0.194 - 0.35
0.: 98.: 11.1 - - - - -	50 +- 0.15 99 1000 117 957 	101.03 12.000 3.018 0.003 1.948 - 1.866 0.095 0.523	91.80 4.000 - 0.052 0.075 0.010 3.763 - 0.005	3.000 99.49 0.980 0.003 1.011 0.008 0.015	9.43 ↔ 0.54 95.62 22.000 5.470 0.741 2.515 - - 2.758 0.005 2.085	1.75 ← 0.28 97.93 23.000 6.171 0.380 2.232 - 2.400 0.017 - 970	0.37 +- 0.2 100.03 32.000 10.197 0.016 5.785 - 0.194 - 0.35
98.9 32.0 11.1 - - - - -	99 100 117 - 357 - - -	101.03 12.000 3.018 0.003 1.948 - - 1.866 0.095 0.523	91.80 4.000 0.052 0.075 0.010 3.763 -	99.48 3.000 0.980 0.003 - 1.011 0.008 0.016	95.62 22.000 5.470 0.741 2.515 - 2.758 0.005 2.085	97.93 23.000 6.171 0.380 2.232 - 2.400 0.017 1.930	100.03 32.000 10.197 0.016 5.765 - 0.194 - 0.35
32.0 11.1 - - - -	100 117 	12.000 3.018 0.003 1.948 - 1.866 0.095 0.523	4.000 - 0.052 0.075 0.010 3.763 -	3.000 0.980 0.003 - 1.011 0.008 0.016	22.000 5.470 0.741 2.515 - 2.759 0.005 2.085	23.000 6.171 0.380 2.232 - 2.400 0.017 1.020	32.000 10.197 0.016 5.785 - 0.194
32.0 11.1 	100 117 357 	12.000 3.018 0.003 1.948 - 1.866 0.095 0.523	4.000 - 0.052 0.075 0.010 3.763 -	3.000 	22.000 5.470 0.741 2.515 - 2.758 0.005 2.085	23.000 5.171 0.380 2.232 - 2.400 0.017 1.820	32.000 10.197 0.016 5.785 - 0.194 -
11.1 	117 - 957 - -	3.018 0.003 1.948 - 1.866 0.095 0.529	0.052 0.075 0.010 3.763 0.005	0.980 0.003 - 1.011 0.008 0.015	5.470 D.741 2.515 - 2.759 D.005 2.085	6.171 0.380 2.232 2.400 0.017	10.197 0.016 5.785 - 0.194 -
4.8 - -	- 357 - - -	0.003 1.948 - 1.866 0.095 0.529	0.052 0.075 0.010 3.763 0.005	0.980 0.003 - 1.011 0.008 0.015	0.741 2.515  2.758 0.005 2.085	0.380 2.232 - 2.400 0.017 1.820	0.016 5.785 - 0.194 -
4.8 - -	357 - - - -	1.948 	0.075 0.010 3.763 	0.003 - 1.011 0.008 0.015	2.515 	2.232 - 2.400 0.017 1.920	5.785 - 0.194 -
-	- - - -	1.866 <sup>°°</sup> 0.095 0.529	0.010 3.763 	- 1.011 0.008 0.015	2.758 0.005 2.085	- 2.400 0.017 1.830	- 0.194 - 0.035
-	- - - -	1.866 <sup>°</sup> 0.095 0.529	3.763 - 0.005	1.011 0.008 0.016	2.758 0.005 2.085	2.400 0.017	0.194
-		0.095 0.529		0.008 0.016	0.005	0.017	- 0.035
-		0,529	0.005	0.016	2.085	1 830	0.035
	28				e	1.020	0.033
1.4		0.346	-	-	0.003	1.792	1.556
2.7	· 201	• •		•	0.045	0.700	2.136
0.1	14		-	-	1.859	0.342	0.085
19.9	08	8,005	3.905	2.019	15,483	15.854	20.004
ratios			•				
		0.6147					
		0.1743					
		0.1798					
		0.0311					
26	.1				•		41.2
71	.0						56.5
2	.9						2.2
		22.1	0.1	1.6	43.0	43.1	15.2
. DPX-GT SYM	2	BADMSA-11F. PLA	G MOAT 3	840MSA-	-11F, GT		
MAGNETITE	ŝ	840HSA-11F, IL	IENITE 6	840MSA-	-11F, BIOT		
	8	84DMSA-11F, SP-	CLOUDED PLAG				
:	26 71 2 , DPX-GT SYM , MAGNETITE , TI-AMPH	26.1 71.0 2.9 • OPX-GT SYM 2 • MAGNETITE 5 • TI-AMPH 8	0.0311 26.1 71.0 2.9 22.1 , DPX-GT SYM 2 B4DHSA-11F, PLA , MAGNETITE 5 B4DHSA-11F, ILH , TI-AHPH 8 84DHSA-11F, SP-	0.0311 26.1 71.0 2.9 22.1 0.1 • DPX-GT SYM 2 B4DMSA-11F, PLAG MOAT 3 • MAGNETITE 5 B4DMSA-11F, ILMENITE 6 • TI-AMPH 8 84DMSA-11F, SP-CLOUDED PLAG	0.0311 26.1 71.0 2.9 22.1 0.1 1.6 , DPX-GT SYM 2 B40MSA-11F, PLAG MOAT 3 B40MSA- , MAGNETITE 5 B40MSA-11F, ILMENITE 6 B40MSA- , TI-AMPH 8 B40MSA-11F, SP-CLOUDED PLAG	0.0311 26.1 71.0 2.9 22.1 0.1 1.6 43.0 . OPX-GT SYM 2 B4DMSA-11F, PLAG MOAT 3 B4DMSA-11F, GT . MAGNETITE 5 B4DMSA-11F, ILMENITE 6 840MSA-11F, BIOT . TI-AMPH 8 84DMSA-11F, SP-CLOUDED PLAG	0.0311 26.1 71.0 2.9 22.1 0.1 1.6 43.0 43.1 , DPX-GT SYM 2 B4DMSA-11F, PLAG MOAT 3 B4DMSA-11F, GT , MAGNETITE 5 84DMSA-11F, ILMENITE 6 84DMSA-11F, BIOT , TI-AMPH 8 84DMSA-11F, SP-CLOUDED PLAG

MEAN & STO DEVIATION FOR PHASES FROM HETAGABOROS

	•	,	ſ	4	5	6	7
•	C PY	rey	OPX	CPX	6T	PLAG	AMPH
\$102	50.88 +- 1 13	50.53 +- 0.62	50.9 +- 0.6	51.5 +- 0.	5 38.1 +- 0.	.4 59.3 +- 2.1	41.6 +- 2.4
T102	8 59 Am 0 CC	0.85 4- 0.02	-	•	-	-	2.1 +- 0.6
A1201	2 12 ** 0.00	2 28 4- 0 29	1 0 += 0.1	2.0 +- 0.	3 21.3 +- 0.	.6 25.5 +- 1.6	11.9 +- 1.1
Fe0	14 18 4- 2 01	14 95 4- 0 23	31.7 += 1.2	12.8 +- 0.1	9 29.7 +- 0.	.4 -	18.5 +- 0.7
Hol	0 27 - 0 04	0 28 4- 0.02	0.6 += 0.3	•	1.6 +- 0.	.) -	-
Matt	10 70 += 0.17	10 73 - 0 21	16 0 4- 0 6	11.3 += 0.1	1 4.1 +- 0.	.7 -	9.0 +- 1.1
C=0	19 95 +- 4 50	10.15 - 0.21	0 6 4- 0 3	21.4 += 0.	s.3+-0.	6 7.5 +- 2.0	11.3 +- 0.4
N=20	1.00 +- 0.15	13.26 +- 0.43	u,a +- u.a	1.0 +- 0.1	7 -	7.0 +- 1.3	2.4 +- 0.3
K20	1.00 +- 0.15	0.36 += 0.13	-	-	•	0.3 +- 0.2	0.9 +- 1.1
Tetal.	- 99.79	99.84	100.8	99.9	101.1	99.7	97.7
Cation	•						
0	6.000	6.000	6.000	6.000	12.000	32.000	23.000
Si	1.966	1.935	1.970	1.957	2,990	10.618	6.322
Ti	0.017	0.024	-	-	-	•	0.238
Å1	0 104	0.103	440.0	0.090	1.973	5.307	2,135
Fe2	0.453	0.479	1.026	0.406	1,948	-	2.358
Mo	0.009	0.009	0.020		0.104	•	-
Ma	0.609	0.613	0.924	0.638	0,480	-	2.046
C.	0.913	0.790	0.024	0.871	0,528	1.438	1,840
Na	0.074	0 071		0.074	-	2.429	0.690
ĸ	0.014	-	-		-	0.064	0,171
Sum	4.024	4.025	4.008	4.035	8,023	19.935	15.807
Inter-	element ratios						
XFe	0.2405	0.2532	0.5146	0.2119	0.6367		
XHg	0.3235	0.3240	0.4635	0,3333	0.1567		
XCa	0.4314	0.4180	0.0121	0.4549	0.1725		
XMn	0.0046	0.0048	0.0099		0.0341		
An						36.6	
Ab						61.8	
0r						1.6	
Mg No.	57.4	56.1	47.4	61.1	19.8		48.2
1 8	40MSA-11F, PRIM C	PX 2	840HSA-11F, PF	RIM CPX(SCAN)	3 840HSA-116,	OPX	
4 8	40HSA-11G, CPX	5	840HSA-116, 61	r	6 840HSA-110	REXT PLAG	
78	40MSA-110, TI-AMP	н					

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	1	2	3	4	5	6	7
	BIOT	CPX	OL	OPX	ST	CPX	AMPH
\$102	35.5 +- 0.6	51.4 +- 1.3	33.09 +- 0.17	50.98 +- 0.62	38.22 +- 0.5	ie 52.55 +- 3.15	40.35 +- 0.30
T102	5.6 ++ 0.3	0.4 +- 0.8	0.01 +- 0.03	0.08 +- 0.05	0.06 +- 0.0	2 0.31 +- 0.07	4.03 +- 0.18
A120	3 14.1 +- 0.5	2.2.+- 1.2	0.01 +- 0.03	1.36 +- 0.25	21.54 +- 0.2	2.75 +- 0.05	12.79 +- 0.76
Cr20	3 -	-	0.01 +- 0.03	0.01 +- 0.03	0.01 +- 0.0	13 0.01 +- 0.03	0.04 +- 0.11
F+0	19.8 +- 1.7	12.7 +- 0.8	49.71 +- 0.64	28.42 +- 0.87	27.80 +- 0.2	8 11.94 +- 1.98	16.58 +- 0.34
MnG	-	0.2 - 0.4	0.50 +- 0.12	0.40 +- 0.07	1.16 +- 0.0	0.24 +- 0.10	0.11 +- 0.04
MgQ	10.8 +- 1.3	11.5 +- 0.5	17.07 +- 0.44	18.47 +- 0.74	5.87 +- 0.1	8 12.65 +- 1.02	8,99 += 0,47
CaO	-	21.3 +- 1.2	0.02 +- 0.05	0.53 +- 0.25	6.17 +- 0.3	3 19.65 +- 0.51	10.87 +- 0.89
Na20	0.2 +- 0.5	0.9 +- 0.3	-	- +- 0.02	-	1.13 +- 0.31	2.55 +- 0.38
K20	9.7 +- 0.6	- +- 0.2	-	-	-	-	1.73 +- 0.44
Teta	l 96.1	100.7	100.42	100.25	100.83	101.24	98.04
Cati						·	22.000
0	22.000	6.000	4.000	8.000	12.000	6.000	23.000
Si	5.473	1,941	0.990	1.952	2.974	1.350	0.103
Ti	0.639	0.011	-	0.002	0.004	0.009	2 281
A1	2.545	0.099	-	0.061	1.9/6	U. 121	0.005
Cr		-	- ·	-	0.001	0 371	2.098
F+2	2.529	0.402	1.244	0.910	1.803	0.3/1	0.014
Mn	-	0.006	0.013	0.013 .	0.076	0.008	2 028
Hg	2.457	0.645	0.761	1.054	0.681	0.701	1.762
Ca	-	0.861	0.001	0.022	0.514	0.701	0.748
Na	0.050	0.066	· • .	-	-	0.001	0.334
ĸ	1.892	0.001	<u>.</u>	-	-	4 021	15.834
Sum	15.586	4.032	3.009	4.015	9.UJ4	4.021	
Inte	-element ratios				a 6072	0.1997	
XFe		0.2099		0.4553	0.3012	0.3764	
XMg	•	0.3371		0.5274	0.2210	0.4202	
XCa		0.4500		0.0109	0.1014	0.0041	
XHa		0.0030		0.0065	37 3	65.4	49.1
Mg N	r. 49.3	61.6	38.0	53.7	41.4		
1	840MSA-11G, BIOT	2	840MSA-11G, PR	IN CPX 3	850MSA-138,	OLIVINE	
4	850MSA-138, OPX	5	85DHSA-138, GT	6	+ BEI - ACHICO	FRAIL GEA	
7	850HSA-138, TI-AM	IPH					

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MEAN & STO DEVIATION FOR PHASES FROM METAGABOROS

					5	6	7
	1	2	3	т та	MAG	06	81
	OL.	OPX	PLAG		-	-	36.90 +- 2.22
\$102	33.46 +- 0.44	51.90 +- 0.45	61.64 +- 1.61		0.44 +- 0.0	3 51.91 +- 0.19	6,39 +- 1.78
T102	-	-	-	0.06 +- 0.04	0.36 +- 0.0	3 0.06 +- 0.13	14.43 +- 1.53
A1201	3 -	1.49 +- 0.21	24.42 +- 0.89	21.36 +- 0.36	0.66 +- 0.0	6 0.02 +- 0.08	0.06 +- 0.08
Cr203	3 -	-	-	-	90.45 += 0.5	4 47.15 +- 0.54	16.92 +- 4.75
Feû	48,89 +- 0,43	27.64 +- 0.67	-	21.81 += 0.03	0.06 += 0.0	4 0.40 +- 0.07	-
Mnū	•	0.45 +- 0.04	-	7.71 - 0.03	-	0.70 +- 0.16	12.30 +- 4.57
MgQ	17.93 +- 0.34	18.66 +- 0.57	•	3.14 +- 0.80	_	•	0.03 +- 0.11
CaQ	0.01 +- 0.02	0.55 +- 0.22	6.00 +- 1.25	6.40 +- U.JI	-	-	0.22 +- 0.15
Na20	•	-	7.89 +- 0.87	•	-	-	9.45 +- 0.33
K20	-	•	0.45 +- 0.17	•		100 24	96.70
Total	l - 100.29	100.69	100.41	101.52	31.37	100.24	
Catio	ans.				4 000	12.000	22.000
0	4.000	6.000	32.000	12.000	4.000	-	5,494
51	0.995	1.967	10.908	2.994		1.976	0.716
Ti	-	-	-	0.003	0.017	0.007	2.532
A1	-	0.067	5.094	1.962	0.022	0.007	0.007
Cr	-	-	-	-	0.027	1 975	2.107
F+2	1.216	0.876	-	1.796	3.890	0.074	-
Mn	-	0.014	-	0.077	0.003	0.054	2.730
Mg	0,795	1.054	-	0.661	•	0.105	0.005
Ca	-	0.022	1.138	0.529	•	-	0.064
Na	-	-	2.707	-	-	-	1,795
ĸ	-	-	0.104	-	-	8.060	15.450
Sum	3.005	4.000	19.951	8.022	3,928	•	
Inte	r-element ratios						
XFe		0.4454		0.5864			
XHg		0.5359		0.2157			
XCa		0.0114		0.1729			
XHn		0.0073		0.0250			
An			20.0				
Ab			68.6	•			
0-			2.6			2.6	54.4
Mg N	e. 39.5	54.6		26.9			
			840MS4-12H. 0P	C Y	84DMSA-13M.	PLAG HOAT	
!	BAUMSA-TOM, OLIVIN			GNETITE E	840MSA-13H.	ILMENITE	
•	84UMSA-13M, GT	2	SANUSA-ISUI NA				
7	84DMSA-13H, BIOT						

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	1	2	3	4	5	6	7
	AMPH	CPX	CPX	PLAG	SPIN	OPX	CPX
Si02	40.67 +- 0.	73 52.60 +-	0.32 52.06 +- 1	1.02 59.68 +- 2.40	0.03 +- 0.03	51.2 +- 0.1	51.2 +- 0.5
T102	3.85 +- 0.5	52 0.50 +-	0.55 0.16 +- (	).22 <b>-</b> .	0.10 +- 0.49	-	0.3 +- 0.2
A120	13 13.43 +- 0.1	68 2.75 +-	0.27 2.25 +- 1	0.59 25,18 ++ 1.01	56.51 +- 1.60	1.8 +- 0.3	3.0 +- 0.5
Cr20	3 0.04 +- 0.º	10 0.01 +-	o.na - +- (	1.02 -	- +- 0.03	-	-
F+0	16.23 +- 1.	05 11.30 +-	1.81 12.48 +- 1	1.10 -	37.09 +- 1.10	28.4 +- 1.2	12.7 +- 1.5
Hn0	0.13 +- 0.3	21 0.23 +-	0.01 0.23 +- (	).07 -	0.15 +- 0.11	0.3 +- 0.5	0.1 +- 0.3
MgQ	9.22 +- 0.3	33 12.32 +-	0.75 11.38 +- 0	3.46 -	4.68 +- 0.85	18.0 +- 0.2	11.2 +- O.B
CaO	- 11.10 +- 0.1	22 20.17 +-	1.26 20.25 +- (	<b>7.29 +- 1.46</b>	0.08 +- 0.08	0.7 + 0.2	20.1 +- 1.2
Na20	2.54 +- 0.3	22 1.02 +-	0.30 1.02 +- 0	).13 7.20 +- 0.79	0.02 +- 0.03	0.2 +- 0.6	1.3 +- 0.3
K20	1.71 +- 0.3	27 -	- +- 0	0.38 +- 0.08	-	-	-
Teta	1 98.92	100.90	99.83	99.73	98.66	100.5	99.8
Cati	ons						
0	23.000	6.000	S.000	32.000	4.000	6.000	6.000
Si	6.082	1.955	1,969	10.674	0.001	1.953	1.940
Ti 👘	0.433	0.014	0.005	-	0.002	-	0.009
A1	2.367	0,120	0.100	5,308	1.926	0.080	0.134
Cr	, 0.005	-	<b>-</b> '	-	-	-	-
F+2	2.030	0.351	0.395	• '	0.897	0.907	0.402
Mn	0.016	0.007	0.007	• `	0.004	0.010	0.003
Mg	2.055	0.683	0.642	-	0.202	1.024	0.635
Ca	1.779	0,803	0.821	1.397	0.002	0.027	0.815
Na	0.737	0.074	0.075	2.497	0.001	0.013	0.093
ĸ	0.326	<b>-</b> .		0.087	-	-	-
Sum	15.830	4.007	4.013	19,963	3.035	4.014	4.031
Inter	-element ratios					,	
XFe		0.1904	0.2117			0.4610	0.2166
XNg	•	0.3701	0.3441			0.5202	0.3422
XCa	•	0.4355	0.4402			0.0139	0.4395
XNn		0.0039	0.0040			0.0049	0.0017
An				35.1			
ÅЪ				62.7			
0+				2.2			
Mg No	. 50.3	66.0	61.9		18.4	53.0	61.2
1	840MSA-13M, TI-A	мрн	2 84DMSA-13H,	PRIM CPX 3	640MSA-13H, CP	X INCL IN PLO	
4	840MSA-13H. PLAG	LATH	5 840MSA-13H,	SPINEL B	850MSA-13P, 0P	X	
7	850MSA-13P. REXT	CPX					

MEAN & STO DEVIATION FOR PHASES FROM METAGABBROS

	1	,	3	4	5	8	7
	et.	CPY	PLAG	AMPH	01.	CPX	PLAG
\$102	) 395.	04 514 - 05	60.8 +- 2.7	40.4 +- 0.3	33.55 +- 0.47	51.97 +- 0.46	61.27 +- 0.58
T102	, ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	A.D F.D.	- +- 0.2	3.7 +- 0.4	- +- 0.01	0.31 +- 0.07	-
1120		0.3 = 0.7	74 1 += 1.9	13.1 +- 0.4	-	3.04 +- 0.30	23.65 +- 0.96
C-20	······································	0.3 2.1 +- 0.3		•	0.01 +- 0.04	0.02 +- 0.04	<b>-</b> .
5.0	27 8 4-	1 2 12 5 An 2 0	- +- 0.2	16.0 +- 0.8	48.41 +- 1.13	10.84 +- 1.01	•
Hell	1 1 4- 1		-	•	0.34 +- 0.06	0.14 +- 0.04	-
Maß	1.1 += 0 5 5 5 - 1		-	8.9 +- 1.0	17.94 +- 0.99	11,96 +- 0.43	•
f0	5.4 += (		5 9 - 2.4	11.1 +- 0.4	0.01 +- 0.03	20.96 +- 0.06	5.63 +- 0.41
N-20		1 20.2 0-0.0	7 8 4- 1.1	2.6	0.02 +- 0.11	1.14 +- 0.08	7.78 +- 0.43
120		1.3 += 0.5	0.6 += 0.3	2.0 +- 0.4	•	-	0.50
Teta	1 100.8	100.0	99.3	98.0	100.28	100.38	96.03
Cati	one						
0	12.000	6.000	32.000	23.000	4.000	6.000	32.000
Si	3.002	1,946	10.895	6,112	0.997	1.944	10.333
Ti	-	0.008	0.005	0.415	-	0.009	
Al	1.956	0,120	5.069	2.345	-	0.134	5.004
Cr	-	-	-	-	•	0.001	-
F+2	1.811	0.395	0.006	2.024	1.203	0.339	
Xn -	0.073	0.006	-	-	0.009	0.004	-
Hg	0.623	0.629	-	2.018	0.794	0.557	1 003
Ca	0.555	0.833	1.142	1.807	-	0.840	9 708
Na	-	0.098	2.708	0.763	0.001	0.081	2.108
ĸ	-	-	0.128	0.396	-		0.115
Sum	6.020	4,035	19.973	15.880	3.004	4.021	19.310
Inte	r-element ratio	5				D.1633	
XFe	0.5915	0.2121				0.3604	
XHg	0.2035	0.3378				0.4540	
XCa	0.1812	0,4470				0.0024	
XMn	0.0237	0.0031					27.7
An			28.7				69.3
AD			68.1				2.9
UP			3.2		19 8	66.3	
rig N	o. 25.6	61.4		43.3	33.4		
1	850HSA-13P, 61	r 2	850MSA-13P, P	RIM CPX 3	BSOHSA-13P, P	LAG	
4	BSDHSA-13P, TI	(-AHPH 5	850MSA-165, 0	. 6	850HSA-165, C	PX	
7	850HSA-165, PL	AG HOAT					

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	1	2	3	4	5	6	7
	67	11.11	AMPH	CPX	PLAG	OPX	CPX
S102	38.50 +- 0.49	0.01 +- 0.03	40.26 +- 0.60	51.89 +- 0.46	57.90 +- 1.56	54.49 +- 0.27	52.37 +- 2.25
T102	0.09 +- 0.22	51.01 +- 0.30	4.49 +- 0.13	0.34 +- 0.03	•	0.06 +- 0.04	0.30 +- 0.56
A120	3 21.41 +- 0.29	0.04 +- 0.03	12.90 +- 0.33	3.10 +- 0.42	26.37 +~ 1.45	0.88 +- 0.32	4.28 +- 2.65
Cr20	3 - +- 0.03	0.06 +- 0.03	0.08 +- 0.18	0.02 +- 0.06	-	-	0.02 ++ 0.09
FeQ.	27.60 +- 1.61	45.79 +- 0.26	16.00 +- 1.12	11.19 +- 1.09	•	19.56 +- 0.38	6.52 +- 1.79
MnQ	0.87 +- 0.12	0.23 +- 0.01	0.06 +- 0.06	0.14 +- 0.07	-	0.13 +- 0.03	0.07 +- 0.22
MaD	5.75 +- 0.26	1.27 +- 0.03	8.99 +- 0.07	11.82 +- 0.64	-	25.49 +- 0.07	13.56 +- 1.48
CaO	6.33 +- 0.49	•	10,96 +- 0.08	20.69 +- 0.95	8.73 +- 1.33	0.50 +- 0.07	21.42 +- 1.83
Na20	•	0.02	2.67 +- 0.16	1.20 +- 0.10	6.27 +- 1.33	0.02 +- 0.06	1.54 +- 0.40
K20	-	-	1.72 +- 0.08	-	0.37 +- 0.12	-	-
Tata	1 100.55	99.43	98.13	100.39	99.64	101,13	100.06
Cati	ens						e 000
0	12.000	3.000	23.000	6.000	32.000	6.000	4 930
SL	2.997	-	6.074	1.943	10,404	1.974	1.328
TL	0.005	0.974	0.509	0.010	•	0.002	0 196
A1 -	1.964	0.001	2.294	0.137	5,585	0.030	0.001
C+		0.001	0.010	0.001	-	-	0.201
F+2	1.797	0.994	2.019	0.350	•	0.333	0.002
Mn	0.057	0.005	0.008	0.004	-	0.004	0.744
Ng	0.667	0.048	2.022	0.660	-	1.110	0 845
Ca	D.529	-	1.772	0.830	1.681	0.013	0.110
Na	-	0.001	0.781	0.087	2,185	0.001	-
ĸ	-	-	0.331 _	-	0.085	4 007	4.025
Sum	8.016	2.025	15.820	4.022	19,939	4.001	
Inte	r-element ratios			•			
XFe	0.5092			0.1900		0.2974	0.1120
XHg	0.2188			0.3576		0.6906	0.4133
XCa	0.1731			0.4500		0.0097	0.4/13
XNo	0.0188			0.0024		<b>a</b> .0020	0.0012
An					42.6		
Ab					55.3		
Or					2.1		78.0
Mg N	a. 27.1 ·	4.6	50.0	65.3		63.3	10.0
1	850HSA-165, GT	2	850MSA-165, IL	H J	850MSA-165, T1	AHP	
4	850MSA-165, PRIM C	PX 5	850MSA-165, PL	AG LATH 6	BSOMSH-SP, OP)	•	
7	850HSH-5F, CPX						

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MEAN & STO DEVIATION FOR PHASES FROM METAGABBROS

	1	2	3	4	5	6	7
	9116	78	11.8	AMPH	CPX	SPIN	OPX
\$102	50.4 += 0.6	39.24 ++ 0.65	-	40.76 +- 0.57	50.81 +- 0.52	0,19 +- 0.32	52.6 +- 0.3
T102		0.01 +~ 0.03	52.96 +- 0.52	3.36 +- 0.46	1,06 +- 0.41	0.01 +- 0.04	•
A120		22 13 Am 0.43	0.01 +- 0.03	15.66 +- 0.96	6.21 +- 2.48	62.41	1.2 +- 0.2
Cr20	13 <b>-</b>	-	0.01 +- 0.04	0.03 +- 0.09	0.11 +- 0.20	•	<b>→</b> + ,
FeD	_	23 39 ++ 0.95	44.14 += 1.33	10.00 +- 0.82	5.89 +- 1.07	22.99 +- 2.79	24.5 +- 0.8
Hoū	-	0 47 += 0.14	0.14 +- 0.07	0.03 +- 0.05	0.03 +- 0.06	0.04 +- 0.10	0.2 + 0.4
Maß	-	9 22 - 0.70	1.75 += 0.06	12.33 +- 0.79	12.77 +- 0.58	13.37 +- 2.07	21.7 +- 0.6
CaO	5 5 am 0 7	6.15 +- 0.67		11.70 +- 0.23	21.86 +- 1.08	0.05 +- 0.13	0.4
Na20		-	-	2.63 +- 0.21	1.58 +- 0.38	-	-
K20	0.3 += 0.1	_	-	1.55 += 0.27	•	-	•
Teta	1 99.4	100.62	99.01	98.05	100.32	99.DG	100.5
Cati	ons						e 000
0	32.000	12.000	3.000	23.000	6,000	6.000 0.00 <b>5</b>	1 964
51	10.804	2,982	-	5.966	1.867	0.005	1,344
ΤL	-	0.001	1.001	0.370	0.029		0.052
AL	5.197	1,982	-	2.702	0.269	1,962	
Cr	-	-	-	0.003	0.003		0.765
F+2	-	1,486	0,920	1.224	0.181	0.313	0.005
Mn	-	0.030	0.003	0.004	0.001	0.001	1.208
Mg	•	1.044	0.066	2.690	0.700	0.001	0.016
Ca 👘	1.265	0.502	-	1.835	0.861	0.001	-
Na	2.584	-	-	0.746	0,113	-	-
ĸ	0.080	-	•	0.289	-		4.010
Sum	19.930	8.027	1,998	15.830	4,024	3.014	
Inte	r-element ratios				A 1039		0.3838
XFe		0.4853			0.1035		0.6058
Xng		0.3410			0.4040		0.0000
XCa		0.1638			0.0005		0.0024
XCO		0.0099			0.0003		
An	32.2						
AQ 0-	63.8						
M- N	2.0			68 7	79.4	50.9	61.2
ng n		41.3	6.8	00.1	(31-		
1	850MSH-SF, PLAG M	DAT 2	BSDMSH-SF, GT	3	ASONSH-SF, IL	7	
4	850MSH-SF, TI-AMP	H 5	OSOMSH-SF, PRIN	1 CPX 6	BSDMSH-SF, SP	INCL	
•			A-	-36			

MEAN	& STO DEVIATION F	OR PHASES FROM M	ETAGABBROS				
	1	2	3	4	5	6	7
	- OPX	OPX	CPX	GT	AMPH	PLAG	0L
\$102	\$1.7 +- 0.8	51.19 +- 0.57	51.39 +- 0.73	38.64 +- 0.35	41.38 +- 0.26	57.0 +- 2.6	i 33.7 +- 0.6
T102	-	0.06 +- 0.03	0.27 +- 0.05	0.03 +- 0.04	2.38 +- 0.27	-	-
A120	3 1.6	1.61 +- 0.49	3.00 +- 0.64	21.62 +- 0.38	12.61 +- 0.28	27.0 +- 1.4	-
C+20	3 -	•	0.07 +- 0.14	0.02 +- 0.08	0.06 +- 0.07	-	-
FeQ	27.8 +- 0.4	27,50 +- 0.87	10.60 +- 1.05	26.67 +- 1.46	16.06 +- 0.56	0.1 +- 0.4	47.3 +- 0.5
MnQ	0.2 +- 0.6	0.50 +- 0.07	0.21 +- 0.05	1.44 +- 0.32	0.09 +- 0.03	-	0.3 +- 0.3
MgQ	18.5 +- 0.4	18,71 +- 0.77	12.16 +- 0.41	5.60 +- 0.46	9.92 +- 0.38	-	19.5 +- 0.6
CaQ	0.4 +- 0.1	0.42 +- 0.10	22.09 +- 0.69	6.97 +- 1.30	11.62 +- 0.15	9.5 +- 1.6	-
Na20	•	-	0.58 +- 0.10	-	1.58 +- 0.08	5.9 +- 1.0	-
K2Q	-	•	-	• .	1.72 +- 0.07	0.3 +- 0.1	-
C1	•	•	-	-	0.04 +- 0.01	-	-
Total	100.3	<b>99.99</b>	100.37	100.99	97.46	99.8	100.8
Catio	ons						
0	6.000	6.000	5.000	12.000	23.000	32.000	4,000
Si	1.967	1.955	1.927	2,993	6.255	10.254	0.989
Ti 👘	-	0.002	0.008	0.002	0.271	-	-
A1	0.072	0.072	0.133	1.974	2.247	5.719	-
Cr	4-	-	0.002	0.001	0.007	-	-
Fe2	0.883	0.878	0.332	1.728	2.030	0.015	1.162
Mn	0.006	0.016	0.007	0.094	0.012	-	0.006
Mg	1.052	1.065	0.580	0.647	2.235	-	0.854
Ca	0.018	0.017	0.868	0.579	1.882	1.834	-
Na	' -	•	0.042	-	0.463	2.050	-
ĸ	-	-		-	0.332	0.080	-
Cl	-	-	-	-	0.010	-	-
Sum	3.998	4.007	4.019	0.019	15.745	13.354	3.011
Inter	-element ratios						
XFe	0.4505	0.4443	0.1744	0.5670			
XMg	0.5368	0.5300	0.3566	0.2122			
XCa	0.0094	0.0067	0.4656	0.1898			
XMo	0.0033	0.0082	0.0035	0.0310			
An						45.3	
Ab						51.7	
0r						2.0	10.0
Mg No	. 54.4	54.8	67.2	27.2	32,4		46.3
1	850MSS-18, OPX	· 2	850HSS-1C, OPX	3	05DHSS-1C, CPX	7 850	MSH-4C, DLIVINE
4	850HSS-1C, GT	5	850MSS-1C, TI-A	MPH 6	850HSS-1C, PLA	3	

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MEAN & STO DEVIATION FOR PHASES FROM METAGABBROS

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		•	•	4	5	6	7
		2	91 AG	6T	CPX	PLAG	AHPH
¥102		E1 8 4 1 1	62 1 An 1.6	38.3 +- 0.5	51.3 +- 0.	6 54.1 +- 4.0	39.5 +- 1.5
3102	31.3 <del>-</del> 4.3			•	0.5 +- 0.	9 -	4.0 +- 0.5
1102	-	0.1 +- 0.3	22.4	21.4 ++ 0.5	3.0 +- 1.	5 27.8 +- 1.8	13.0 +- 1.1
ALZUS	s 1.2 += 4.1	3.2 +- 0.7	23.4	27.6 += 0.4	10.1 +- 1.	2 3.4 +- 2.0	15.4 +- 0.5
FeU M-0	26.6 +- 0.8	9.7 +- 1.1	U.J	0.7 += 0.3	0.1 +- 0.	<b>- t</b>	-
	0.1 +- 0.4	-	-	6.2 Am R.6	12.0 +- 0.	8 0.8 +- 0.6	9.9 +- 0.5
ngu	19.9 +- 0.5	12.3 +- 0.4		S S an 0.2	21.3 - 1.	6.2 +- 0.7	10.6 +- 3.2
Lau	0.4 + 0.1	21.3 +- 1.6	4.8 +- 0.8	-	1.4 +- 0.	4 5.6 +- 0.6	2.5 +- 0.5
NaZU	•	1.4 += U.4	8.1 +- 0.4	-	-	0.3 +- 0.1	2.1 +- 2.1
K20	-	-	U.3 += 0.3	400 7	99.6	99.3	96.9
Total	99.6	99.6	99.0	100.7	2310		
Catio	in#		-		e 000	32.000	23.000
0	6.000	6.000	32.000	12.000	4 473	9.905	S.033
51	1.963	1.943	11.104	2,976	1.333	-	0.463
ΤL	•	0.003	•	-	0.015	E 009	2,333
AL	0.052	0.140	4.932	1.961	0.132	0.527	1,969
F+2	<b>G.847</b>	0.303	0.045	1.797	0.000	-	•
Mn	0.005	-	•	0.049	0.002	n. 227	2.245
Mg	1.131	0.686	•	0.723	0.8/3	1.218	1.728
Ca	0.015	0.858	0.920	0.238	0.862	7.329	0.731
Na	-	0.099	2.791	-	0.101	0.079	0.403
ĸ	-	-	0.068	-	-	20.295	15.905
Sum	4,011	4.033	19.860	8.043	4,036	20.273	
Inter	-element ratios						
XFe	0.4241	0.1642		0.5783	0.1710		
XHg	0.5663	0.3715		0.2328	0.3631		
XCa	0.0074	0.4643		0.1734	0.4649		
XMn	0.0023			0.0157	0.0010	<b>13 B</b>	
An			24.3			01.5	
Ata			73.9			3 3	
Or			1.8			6.E 30.4	K7 1
Mg No	57.2	69.3		28.7	68.0	JU. (	
1	850MSH-4C. OPX	2	850MSH-4C, CPX	: :	850MSH-4C.	PLAG HOAT	
4	850MSH-4C. GT	5	. 850HSH-4C, PRI	IN CPX	B 850HSH-4C.	PLAG SCANLEUT	
7	850HSH-4C, TI-AHPI	H					

	1	2	з	4	5	5	7
	BIOT	OL	OPX	CPX	67	11.	N PLAG
\$102	35.8 +- Q.9	35.17 +- 0.56	52.80 +- 0	0.86 52.40 +- 1	.04 39.06 +-	0.55 0.02 +	- 0.06 58.67 +- 1.39
T102	7.2 +- 0.4	0.01 +- 0.04	0.05 +- 4	0.07 0.11 +- 0	.i1 0.09 +-	0.28 50.87 +	- 1.78 0.07 +- 0.12
A1203	14.4 +- 0.7	•	1.43 +- 1	0.51 3.59 +- 1	.89 21,50 +-	0.99 0.05 +	- 0.07 25.97 +- 1.05
Cr203	-	-	0.01 +- 8	0.04 0.07 +- 0	.02 0.04 +-	0.16 0.05 +	- 0.13 0.02 +- 0.03
FeQ	16.1 +- 2.0	38.61 +- 1.83	21.49 +- 1	1.09 8.18 +- 0	.80 24.57 +-	1.62 45.67 +	- 0.65 0.19 +- 0.35
MnQ	-	0.23 +- 0.14	0.20 +- 0	0.09 0.05 +- 0	.10 0.61 +-	0.18 0.15 +	- 0.06 - +- 0.02
MgÖ	12.5 +- 0.8	26.30 +- 1.96	23.33 +- (	0.87 13.14 +- 0	.68 7.65 +-	0.59 2.01 +	- 0.10 0.02 +- 0.06
CaO	-	-	0.34 +- 0	0.23 20.85 +- 0	.60 6.32 +-	0.47 0.01 +-	- 0.03 7.73 +- 0.96
Na20	0.6 +- 0.2	-	0.02 +- 0	0.05 1.51 +- 0	.10 0.05 +-	0.22 -	7.22 +- 0.43
K20	9.8 +- 0.2	-	-	0.02 +- 0	.07 0.01 +-	0.06 -	0.35 +- 0.21
Tetal	96.4	100.32	99.67	99.92	99.90	98.83	100.24
Cation	•						
0	22.000	4,000	6.000	6,000	12.000	3.000	32.000
S1	5.368	0.990	1.961	1.945	3.012	0.001	10.484
T1	0.808	-	0.001	0.003	0.005	0.972	0.009
A1	2.538	•	0.063	0.157	1.954	0.001	5.470
Cr	۰ <u>ـ</u>	-	-	0.002	0.002	0.001	0.003
F+2	2.014	0.909	0.668	0.254	1.585	0.971	0.028
Mn	-	0.005	0.006	0.002	0.040	0.003	-
Mg	2.799	1.104	1.292	0.727	0.879	0.076	0.005
Ca	-	-	0.014	0.829	0.522	-	1,480
' Na	0.183	-	0.001	0.109	0.007	-	2.502
ĸ	1.873	-		0.001	0.001	-	0.080
Sum	15.583	3.009	4.006	4.028	8,009	2.026	20.061
Inter-e	element ration						
XFe			0.3373	0.1402	0.5236		
XHg	•		0.6527	0.4013	0.2906		
XCa	•		0.0068	0.4577	0.1726		
XMn			0.0032	0.0009	0.0132		
An							36.4
Ab							61.6
Or							2.0
Hg No.	58.2	54.8	65.9	74.1	35.7	7.3	15.8
1 85	IDMSH-4C, BIOT	2	850HSH-4G. (		3 850MSH-40,	OPX .	
4 85	IOHSH-4G, CPX	5	850HSH-48, 0	GT	6 850MSH-46	ILMENITE	
7 85	OMSH-46, SP-CLOU	DED PLAG					

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MEAN & STO DEVIATION FOR PHASES FROM METAGABOROS -

	•	,	3	4	5	6	7
	AMDU	4. 114	PLAG	OL.	OPX	CPX	GT
\$102	40.35 +- 1.20	4.21 +=12.12	53.4 +- 5.3	33.91 +- 1.33	52.29 +- 0.86	52.56 +- 1.24	38.82 +- 0.39
T(02	3 61 4- 0 71	0.01 += 0.05	0.1 +- 0.4	0.01 +- 0.06	0.01 +- 0.03	0.20 +- 0.97	0.04 + 0.02
A1203	14 30 - 0.00	56 12 ++ 6.59	28.1 += 3.2	- +- 0.03	0.92 +- 0.30	J.22 +- 0.71	21.50 +- 0.27
C-203		0.04 += 0.09	-	-	-	-	•
5-0	12 05 - 1 63	28.49 += 4.97	3.3 +- 2.8	47.28 +- 5.03	26.88 +- 3.40	10.56 +- 2.32	26.96 +- 1.80
MnD	0.08 += 0.11	0.09 += 0.08	-	0.36 +- 0.06	0.32 +- 0.05	0.22 +- 0.71	0.84 +- 0.09
Maß	11 64 40 0 72	8 95 += 2.11	1.1 +- 1.3	18.98 +- 3.92	19.35 +- 2.13	11.77 +- 1.25	\$.55 +- 1.32
(	11.39 - 0.12	0.47 += 1.20	6.7 += 0.7	0.06 +- 0.29	0.45 +- 0.14	20.20 +- 1.47	7.27 +- 2.38
N-20	2 97 4- 0 10	0.54 += 1.63	6.3 +- 0.8	-	0.02 +- 0.04	1.63 +- 0.35	-
820	1 14 4- 0.00	0.10 += 0.18	0.4 += 0.5	-	•	•	-
Tabal	1.14 - 0.03	0.10 *** 0.10	99 1	100.60	100.23	100.36	100.98
IOCAL	37.62	33.03	33.4				
				•			
0	00 CC	4 000	32 000	4.000	6,000	6.000	12.000
с.	5.000	0.116	9.792	0.997	1.982	1.960	3.005
74	9.334	-	0.008	•	-	0.006	0.002
A1	2 504	1.811	6.069	-	0.041	0.142	1.962
 Cr	0.011	0.001	-	-	•	-	•
F2	1 497	0.652	0.509	1.163	0.852	0.329	1,743
Mn	0.010	0.002	-	0.009	0.010	0.007	0.055
Ma	2.578	0.365	0.290	0.832	1.093	0.654	0.640
C.	1.813	0.014	1.322	0.002	D.018	0.807	0.603
Na	0.855	0.029	2.226	•	0.001	0.116	-
ĸ	0.216	0.003	0.105	-	-	•	-
S	15 881	2.994	20.330	3.003	3.998	4.023	8,01Z
	13.001	<b>Q</b> ,,					
Inter	alement ratios						
XFe					0.4317	0.1032	0.5734
XMa					0.5539	0.3640	0.2104
XC.					0.0093	0.4490	0,1301
Xiin					0.0052	0.0039	0,0181
An			36.2				
Ab			60.9				
0r			2.9				26.8
Ha No.	. 63.3	35.9	36.9	41.7	56.2	68.5	****
1 1	SOMSH-4G. TI-AMPH	2	850MSH-4G, SPI	NEL 3	850HSH-40, PL	LG SCANLEDI	
4 1	SOMSH-101C, QLIVI	NE S	BSDMSH-101C, 0	PX 6	850MSH-101C, 1	PX	
7	SOMSH101C, GT		Δ-7	88			

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	1	2	3	4	5	6	7
	SYM	B1	Амри	CPX	PLAG	OPX	PLAG
S102	40.47 +- 1,76	36.39 +- 0.65	41.48 +- 0.47	51.64 ++ 1.12	55.94 +- 4.45	50.4 +- 0.7	59.8 +- 2.5
T102	0.02 +- 0.05	3.94 +- 4.38	1.09 +- 0.48	1.20 +- 0.49	0.09 +- 0.16	-	-
A1203	19.10 +- 2.59	14.60 +- 0.94	13.75 +- 0.50	2.80 +- 0.42	26.67 +- 3.00	0.9 +- 0.2	24.8 +- 0.4
F+O	25.84 +- 2.41	17.32 +- 2.41	14.01 ++ 0.20	11.01 +- 0.99	2.86 +- 3.11	30.5 +- 0.8	0.5 +- 0.3
NnQ	0.85 +- 0.16	0.02 +- 0.04	0.05 +- 0.02	0.18 +- 0.05	-	0.2 + 0.4	-
Mg0	6.38 ++ 1.38	13.48 +- 4.16	11.61 +- 0.13	11.90 +- 0.95	0.59 +- 0.66	16.9 +- 0.B	-
CaO	8.08 +- 2.08	0.05 +- 0.10	11.44 +- 0.17	20.33 +- 0.62	6.02 +- 1.56	0.4 +- 0.1	6.8 +- 0.7
Na20	0.15 +- 0.15	0.30 +- 0.07	2.73 +- 0.17	1.35 +- 0.29	6.90 +- 0.61	-	7.3 +- 0.6
K20	-	9.33 +- 0.76	1.34 +- 0.04	-	0.52 +- 0.46	-	0.3
Total	100.09	95.43	97.50	100.41	99.59	99.3	99.4
Cation	•						
0	12.000	22.000	23.000	6.000 ·	32.000	6.000	32.000
51	3.125	5.506	. 6.206	1.934	10.176	1.969	10.736
Ti	9.001	0.448	0.123	0.034	0.012	-	-
A1	1.739	2.604	2.425	0.124	-5,718	0.040	5.237
Fe2	1.669	2.192	1.753	0.345	0.435	0.997	0.075
Mn	0,056	0.003	0.006	0.006	-	0.007	•
Mg	0.734	3.040	2.589	0.664	0.160	0.984	-
Ca	0.669	0.008	1.834	0.816	1.173	0.017	1.298
Na	0.022	0.088	0.792	0.090	2.434	•	2.541
ĸ	-	1.801	0.256	-	0.121	-	0.057
Sum	8.015	15.689	15.983	4.020	20.230	4.012	19.945
Inter-	element ratios		-				
XFe				0.1884		0.4974	
XMg				0.3629		0.4909	
XCa				0.4456		0.0084	
XHn				0.0031		0.0033	
Ån					31.5		33.3
Аb					65.3		65.2
0e -					3.2		1.5
Mg No.	30.6	58.1	59.6	65.8	26.9	49.7	
1 85	50MSH-101C, GT SYN	1 2	850MSH-101C, 81	DT 3	850MSH-101C, T	E-AMPH	
4 85 7 85	50MSH-101C, CLEAR 50MSR-22, PLAG MON	PLAG 5 NT	BSDHSH-101C, SP	-CLOUDED PLAG 6	850MSR-22, 0PX		

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MEAN & STO DEVIATION FOR PHASES FROM METAGABOROS

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6T         CPX         PLAG         AMPH         OL         OPX         T           S102 $37.7 \div 0.7$ $49.9 \div 2.2$ $59.3 \div 0.1$ $40.8 \div 0.5$ $36.08 \div 0.50$ $53.566 \div 0.66$ $53.51$ TiO2         -         0.9 \div 1.2         - $2.0 \div 0.2$ $0.04 \div 0.03$ $0.10$ A1203 $21.2 \div 0.7$ $3.5 \div 2.8$ $25.2 \div 0.6$ $12.7 \div 0.7$ $ 1.20 \div 0.40$ $3.16$ Fe0 $29.9 \div 1.2$ $12.5 \div 1.1$ $0.2 \div 0.4$ $17.2 \div 1.5$ $36.97 \div 1.57$ $21.22 \div 1.03$ $7.09$ Mn0 $0.9 \div 0.3$ $0.1 \div 0.3$ -         - $0.17 \leftarrow 0.09$ $0.16 \div 0.05$ $10.77$ Mg0 $4.5 \div 1.1$ $11.9 \div 0.8$ - $9.5 \div 1.0$ $27.61 \div 1.40$ $23.62 \div 0.59$ $13.71$ Ca0 $6.5 \div 1.0$ $20.2 \div 2.4$ $7.2 \div 0.3$ $11.7 \div 0.1$ $0.02 \div 0.623$ $21.40$ Na20         - $0.9 \div 0.8$ $7.0 \div 0.3$ $1.9 \div 0.3$ - $- $ $- $ $- $ $- $ $- $ $-$	7
Si02 $37.7 + 0.7$ $49.9 + -2.2$ $59.3 + 0.1$ $40.8 + -0.5$ $36.08 + -0.50$ $53.66 + -0.64$ $53.51$ Ti02       - $0.9 + -1.2$ - $2.0 + -0.2$ - $0.04 + 0.03$ $0.10$ A1203 $21.2 + -0.7$ $3.5 + 2.8$ $25.2 + -0.6$ $12.7 + -0.7$ - $1.20 + -0.40$ $3.16$ Fe0 $29.9 + -1.2$ $12.5 + -1.1$ $0.2 + -0.4$ $17.2 + -1.5$ $36.97 + -1.57$ $21.22 + +0.03$ $7.09$ Mn0 $0.9 + -0.3$ $0.1 + -0.3$ -       - $0.17 + -0.03$ $0.16 + -0.03$ $10.709$ Mg0 $4.5 + -1.1$ $11.9 + -0.8$ - $9.5 + -1.0$ $27.61 + -1.40$ $23.62 + -0.53$ $13.71$ Mg0 $5 + -1.0$ $20.2 + -2.4$ $7.2 + -0.3$ $11.7 + -0.1$ $0.02 + -0.03$ $0.50 + -0.63$ $21.40$ Ns20       - $0.9 + -0.8$ $7.0 + 0.3$ $1.9 + -0.3$ - $- + - 0.03$ $1.42$ K20       -       - $0.2$ $1.3 + -0.2$ -       - $ $	PX
3102 $-1.2$ $0.06 + -1.2$ $0.06 + -0.3$ $0.10$ $1102$ $ 0.9 + -1.2$ $2.0 + -0.2$ $0.06 + -0.03$ $0.10$ $1102$ $ 0.9 + -1.2$ $2.5 + -0.6$ $12.7 + -0.7$ $ 1.20 + -0.40$ $3.16$ $1102$ $-2.9 + -1.2$ $12.5 + -1.1$ $0.2 + -0.6$ $12.7 + -0.7$ $ 1.20 + -0.40$ $3.16$ $1100$ $0.9 + -0.3$ $0.1 + -0.3$ $  0.17 + -0.03$ $0.16 + -0.04$ $0.07$ $1100$ $0.9 + -0.3$ $0.1 + -0.3$ $ 9.5 + -1.0$ $27.61 + -1.40$ $22.62 + -0.59$ $13.71$ $1100$ $4.5 + -1.1$ $11.9 + -0.8$ $ 9.5 + -1.0$ $0.02 + -0.03$ $0.50 + -0.63$ $21.40$ $1100$ $0.9 + -0.8$ $7.0 + -0.3$ $1.9 + -0.3$ $                         -$ </td <td>+- 0.34</td>	+- 0.34
1102       0.15 $1.2$	+- 0.05
Alds       21.2 $40.1$ $10.5$ $10.2$	+- 0./3
$23.5 \neq 0.12$ $12.5 \neq 0.11$ $12.5 \neq 0.11$ $12.5 \neq 0.11$ $10.5 \neq 0.03$ $0.17 \neq -0.03$ $0.16 \neq -0.04$ $0.07$ Mn0 $0.9 \neq -0.3$ $0.1 \neq -0.3$ $ 9.5 \neq -1.0$ $27.61 \neq -1.40$ $23.62 \neq -0.59$ $13.71$ Mg0 $4.5 \neq -1.1$ $11.9 \neq -0.8$ $ 9.5 \neq -1.0$ $27.61 \neq -1.40$ $23.62 \neq -0.59$ $13.71$ Ca0 $6.5 \neq -1.0$ $20.2 \neq -2.4$ $7.2 \neq -0.3$ $11.7 \neq -0.1$ $0.02 \neq -0.03$ $0.50 \neq -0.63$ $21.40$ Na20 $ 0.9 \neq -0.8$ $7.0 \neq -0.3$ $1.9 \neq -0.3$ $  -$ <td>+- 0.07</td>	+- 0.07
$H_{00}$ $0.5 \neq 0.13$ $0.1 \neq 0.03$ $0.1 \neq 0.03$ $0.1 \neq 0.03$ $0.1 \neq 0.03$ $13.71$ $Mg0$ $4.5 \Rightarrow -1.1$ $11.9 \Rightarrow -0.8$ $ 9.5 \Rightarrow -1.0$ $27.61 \Rightarrow -1.40$ $23.62 \Rightarrow -0.59$ $13.71$ $Ca0$ $6.5 \Rightarrow -1.0$ $20.2 \Rightarrow -2.4$ $7.2 \Rightarrow -0.3$ $11.7 \Rightarrow -0.1$ $0.02 \Rightarrow -0.03$ $0.50 \Rightarrow -0.63$ $21.40$ $Na20$ $ 0.9 \Rightarrow -0.8$ $7.0 \Rightarrow 0.3$ $1.9 \Rightarrow -0.3$ $  -$	+- 0.02
Ingle $4.5 + 1.1$ $11.5 + 0.5$ $7.2 + 0.3$ $11.7 + 0.1$ $0.02 + 0.03$ $0.50 + -0.63$ $21.40$ Ca0 $6.5 + 1.0$ $20.2 + 2.4$ $7.2 + 0.3$ $11.7 + -0.1$ $0.02 + -0.03$ $0.50 + -0.63$ $21.40$ Na20       -       0.9 + -0.8 $7.0 + -0.3$ $1.9 + -0.3$ -       -       + - 0.03 $1.42$ K20       -       -       0.2 $1.3 + -0.2$ -       -	+- 0.45
Lau $0.5 \leftarrow 1.0$ $20.2 \leftarrow 2.4$ $1.0 \leftarrow 0.3$ $1.9 \leftarrow 0.3$ $- \leftarrow 0.03$ $1.42$ Nu20       -       0.9 \leftarrow 0.8 $7.0 \leftarrow 0.3$ $1.9 \leftarrow 0.3$ $- \leftarrow 0.03$ $1.42$ K20       -       -       0.2 $1.3 \leftarrow 0.2$ $  -$ Total       100.6       99.8       99.0       97.2       100.85       100.40       100.46	+- 0.14
Na20 - 0.2 1.3 - 0.2 - 1.3 - 0.2 - 0	+- 0.34
R20	
Cations con E DOO	
0 12 000 5.000 32.000 23.000 4.000 6.000 4.000	
54 2 970 1 896 10.663 6.219 0.999 1.374 1.304	
nn 0.063 0.003 - 2.165 1.140 1.295 0.750	
ng 0.529 0.672 1.388 1.916 0.001 0.020 0.842	
K	
Sum 8.046 4.0Jr 19.300 1999.9	
Inter-element ratios 0.1201	
XF+ 0.6342 0.2094 0.6566 0.4141	
XHg 0.1698 0.3553 0.4646	
XCa 0.1758 0.4339 0.0012 0.0025 0.0012	
XMn 0.0202 0.0014	
An - 35.8	
Ab 63.0	
0r 1.2 \$6.5 77.5	
Mg Ne. 21.1 62.9 49.6 57.1 5515	
1 85DMSR-22, GT 2 85DMSR-22, PAIM CPX 3 85DMSR-22, PLAG	
4 850HSR-22, TI-AMPH S 850HSR-28, OLIVINE 6 850HSR-28, OPX	
7 BSDMSR-28, CPX	

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	1	2	3	4	5	6	7
	SYM	GT	CPX	PLAG	AMPH	81	ILM
Si02	41.52 +- 3.66	39.51 +- 0.6	8 50.23 +- 1.8	1 55.20 +- 1.27	41.8 +- 0.6	37.4 +- 1.1	0.4
T102	0.14 +- 0.27	0.04 ++ 0.0	6 2.00 +- 1.3	0 0.12 +- 0.04	2.9 +- 0.2	5.3 +- 1.3	53.6
A1203	19.44 +- 4.55	21.95 +- 0.3	9 4.39 +- 1.9	0 28.27 +- 0.45	13.7 +- 1.1	15.3 +- 1.0	-
Cr203	-	-	-	-	-	- +- 0.3	-
F+O	21.78 +- 3.41	24.68 +- 1.2	5 8.58 +- 1.5	4 2.84 +- 0.67	11.4 +- 0.8	11.9 +- 2.5	45.9 +- 0.6
MnQ	0.48 +- 0.10	0.55 +- 0.0	3 0.09 +- 0.0		-	-	-
MgO	8.73 +- 1.12	7.43 +- 1.0	5 12.48 +- 1.2	1 1.01 +- 0.14	12.4 +- 0.4	16.0 +- 1.9	1.8 +- 0.1
CaO	8.98 +- 3.33	7.37 +- 1.6	8 20.79 +- 1.01	6.68 +- 0.55	11.7 +- 0.3	-	-
Na20	0.25 +- 0.29	-	1.29 +- 0.20	6.68 +- 0.32	3.0 +- 0.3	0.3 +- 0.7	-
K20	-	-	-	0.23 +- 0.07	1.1 +- 0.1	9.9 +- 0.4	-
Total	101.32	101.53	99.85	101.03	98.1	96.2	101.7
Cation							
0	12.000	12,000	· s 000	32,000	23.000	22.000	3.000
Si	3,131	3 001	1 876	9 911	6.142	5.476	0.010
Ti	0.008	1 007	0.056	0.016	0.324	0.577	0.988
A1	1.729	1 965	0.193	5.987	2.380	2.643	-
C.	1_		-	-	-	0.005	•
F2	1 374	1 560	0.259	0 126 .	1.398	1.452	0.941
Mo	0 031	0.035	0.200	-	•	-	-
Ma	0.981	0.841	0.695	0.270	2.718	3.499	0.064
C.	0.726	0.600	D 832	1.285	1.843	-	•
Na	0.037	-	0.093	2.326	0.864	0.091	-
ĸ	-	_	-	0.053	0.212	1.851	-
Sum	8.015	8.014	4.017	20.270	15.882	15,594	2.002
Intern							
XFe	erement ratios	0.5150	1491				
XMa		0.2763	0 3865				
XCa	•	0.1970	0.1629				
XMn		0.0116	0.0016				
An .		0.0110	0.0010	35.1			
Ah				67 5			
0r				1.4			
Mg No.	41.7	34.9	72.2	38.8	66.0	70.7	5.4
1 01				3	ASTMSA-28. PP	IN CPX -	
	50050-20, 01 310 50050-30 60-01000		030030-28, 61 050450-20 TT	1404 Č	850MS8=28. 81/	17	
7 85	50MSR-28, ILMENITE	E PLAG 3	030838-20; 11*	Alifa O			

MEAN & STO DEVIATION FOR PHASES FROM METAGABBROS

	•	2	3	4	5	6	7
		OPX	CPX	SYM	6T	ILN	BIOT
\$102	34.8 += 1.4	53.0	53.1 ++ 1.2	41.06 +- 2.84	38.91 +- 0.1	66 0.2 +- 0.8	36.2 +- 1.3
T102	-	-	•	0.05 +- 0.05	-	52.0 +- 0.7	6.7 +- 0.5
A1203	-	0.8	3.7 +- 0.9	18.72 +- 3.86	21.63 +- 0.3	35 -	14.8 +- 0.9
C+203	_	-	•	<b>-</b> '	-	-	0.1 + 0.3
5-0	44 5 4 6 2	24.7	8.4 += 1.3	23.38 +- 3.79	25.98 +- 2.1	87 47.8 +- 1.3	14.8 +- 0.5
MaQ		-	-	0.64 +- 0.17	0.60 +- 0.1	19 -	•
Matt	21 6 4- 4 1	20.9	12.1 +- 0.8	7.32 +- 1.21	5.76 +- 1.	19 1.1 +- 0.3	13.2 +- 0.5
C=0	-	1.3	20.3 +- 1.1	9.10 +- 2.75	8.09 +- 2.	76 -	-
N-20	-		2.1 += 0.5	0.36 +- 0.47	-	-	0.7 + 0.1
120	_	_		0.01 +- 0.03	-	-	9.7 +- 0.3
Tetal	101.1	100.3	99.9	100.64	100.97	101.2	96.0
Cation						2 400	22 000
0	4.000	6.000	6.000	12.000	12.000	3.000	5 401-
St	0.999	1.984	1.970	3.150	3.002	0.005	0 755
Τi	-	-	-	0.003	-	0.9/6	2.501
Al	-	0.035	0.162	1.693	1.967		0.012
Cr	-	-	•	-	-	- -	1.820
Fe2	1.069	0.761	0.262	1.500	1.676	ų.330 -	-
Hn	0.005	-	-	0.042	0.039	0 041	2.933
Mg	0.927	1.166	0.667	0.837	0.662	0.041	-
Ca	-	0.052	0.806	0.748	0.669	-	0.194
Na	-	-	0.166	0.054	-	-	1 979
ĸ	-	-	-	0.001	-		18 855
Sum	3.001	3.998	4.032	8.028	0.015	2.013	131033
Inter-	element ratios				A 5507		
XFe		0.3844	0.1509		0.3302		
Xng		0.5893	0,3843		0.2195		
XCa		0.0263	0.4640		0.0129		
X70					20.01	3.9	61.7
ng Ne.	46.5	60.5	71.8	33.8	20.J		
1 8	SOMSR-30, OLIVIN	E	2 850HSR-30, 0PX	3	\$50MSR-30,	CPX	
4 8	SOMSA-30, GT SYM	I	5 850MSR-30, GT	6	85DMSA-30,	ILMENITE	
78	SOMSR-30, BLOT						•

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	1	2	Э	4	5	6	7
	AMPH	CPX	PLAG	0L	OPX	CPX	SYM
SiO	2 39.9 +-	0.3 50.1 +- 0.	7 55.48 +- 3.1	1 35.58 +- 1.08	52.71 +- 1	.54 52.26 +- 0.41	44.78 +- 3.31
T102	2 3.5 +-	0.3 1.9 +- 0.	5 0.12 +- 0.1	9 - +- 0'.02	0.05 +- 0	.05 0.12 +- 0.16	0.15 +- 0.27
A120	03 14.0	3.6 +- 0.	8 26.66 +- 2.4	9 - +0.02	1.58 +- 0	.28 3.30 +- 1.21	16.30 +- 4.04
C+20	)3 0.2 +-	0.4 -	-	-	-	-	-
F#O	14.4 +-	0.4 10.1 +- 0.	4 3.06 +- 2.0	7 35.64 +- 0.78	20.18 +- 0	.66 6.92 +- 0.32	19.19 +- 4.23
MnO	-	0.1 +- 0.3	3 -	0.22 +- 0.02	0.21 +- 0	.02 0.09 +- 0.06	0.55 +- 0.20
MgO	9.6 +-	0.4 12.0 +- 1.	4 0.74 +- 0.6	1 28.69 +- 0.64	24.39 +- 0	.41 13.48 +- 0.33	10.14 +- 1.65
CaO	11.4 +-	0.1 20.5 +- 0.1	7 5.10 +- 0.8	6 0.03 +- 0.02	0.33 +- 0	.30 21.57 ++ 0.60	10.81 +- 4.47
Na20	3.1+-	0.3 1.6 +- 0.3	3 7.41 +- 0.7	1 -	-	1.45 +- 0.29	0.40 +- 0.32
K20	1.3 +-	0.4 -	0.48 +- 0.3	9 -	-	-	•
Tota	1 97.2	99.8	99.05	100.16	99.45	99.19	102.32
Cati	one						
0	23.000	6.000	32.000	4.000	6.000	6.000	12.000
Si	6.030	1.888	10.151	0.989	1.952	1,947	3.313
TL	0.398	0.053	0.017	-	0.001	0.003	0.009
<b>A1</b>	2.494	0.159	5.750	-	0.069	0.145	1.421
Cr	40.018	-	<b>-</b> .	-	-	-	-
F+2	1.814	0.319	0.468	0.828	0.625	0.216	1.187
Mn	-	0.003	-	0.005	0.007	0.003	0.034
Mg	2.151	0.672	0.202	1.188	1.346	0.749	1.118
Ca	1:838	0.828	. 1.000	0.001	0.013	0.861	0.857
Na	0.908	0.117	2.629	-	-	0.105	0.057
ĸ	0.241	•	0.112	-	-	-	•
Sum	15.891	4.038	20.328	3.011	4.013	4.029	7.997
Inter	r-element ratio	1					•
XFe		0.1752			0.3139	0.1179	
XHg		0.3683			0.6762	0.4095	
XCa	•	0.4542			0.0066	0.4710	
XMn		0.0018			0.0033	0.0016	
An İ			26.7				
Ab			70.3				
0.			3.0				
Mg Na	. 54.3 <sup>°</sup>	67.8	30.1	58.9	68.3	77.6	48.5
1	850MSR-30, TI-	AMPH 2	850MSR-30, PRI	N CPX 3	850MSR-30,	SP-CLOUGED PLAG	
4	850MSA-82, 0L1	VINE S	85DMSA-82, 0PX	6	850MSR-82, 1	CPX	
7	850MSR-82, GT	SYM					

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MEAN & STO DEVIATION FOR PHASES FROM METAGABBROS

	1	2	3	4	5	6	· 7
	GT	ILN	BIOT	AMPH	CPX	PLAG	OPX
S10	39.20 +- 2.96	0.4 +- 0.1	37.6 +- 0.	.9 41.5 +- 0.9	51.24 +- 2	2.22 55.44 +- 3.60	50.84 +- 0.69
TiO	12 - +- 0.02	53.0 +- 0.6	5.1 +- 0.	.7 3.0 +- 0.2	0.66 +- 0	0.14 +- 0.04	0.06 +- 0.08
A12	21.74 +- 1.96	-	14.6 +- 0.	.5 13.0 +- 0.3	3.13 +- 0	).58 27.39 +- 2.31	0.91'+- 0.46
FeO	23.13 +- 1.69	46.2 +- 1.2	10.4 +- 2.	5 10.7 +- 0.9	7.15 +- 0	1.11 2.57 +- 1.77	31.65 +- 2.33
MnQ	0.68 +- 0.09	0.3 +- 0.1	-	•	0.11 +- 0	).04 -	0.54 +- 0.15
MgO	8.35 +- 0.73	1.4 +- 0.7	17.1 +- 2.	1 12.8 +- 0.6	13.24 +- 0	1.44 1.04 +- 0.67	16.12 +- 1.89
CaO	6.78 +- 1.64	-	-	11.5 +- 0.2	22.17 +- 0	.10 5,93 +- 0.58	0.51 +- 0.20
Na2	0 0.02 +- 0.13	-	0.4 +- 0.	8 3.2 +- 0.4	1.06 +- 0	.84 6.99 += 0.46	-
K20	-	-	9.8 +- 0.	.1 1.0 ++ 0.1	•	0.32 +- 0.06	-
Tet	al 99.90	101.3	95.0	96.0	98.76	99.82	100.63
Cat	lons						
0	12.000	3.000	22.000	23.000	6.000	32.000	6.000
51	3.006	0.009	5.530	6.173	1.926	10.046	1.969
ΤL	-	0.985	0.566	0.341	0.019	0.019	0.002
AL	1.965	-	2.531	2.203	0.139	5.852	0.042
F+2	1.483	0.954	1.277	1.330	0.225	0.390	1.025
Mn	- 0.044	0.007	-	-	0.004	-	0.018
Mg	0,954	0.052	3.758	2.836	0.742	0.281	0.931
Ca	0.557	-	-	1.832	0,893	1.152	0.021
Na	0.003	-	0,120	0.914	0.077	2.457	•
ĸ	-	-	1.831	0.186	-	0.074	-
Sum	8.013	2.006	15.614	15.894	4.024	20.272	4.008
Inte	Prolement ratios						
XFe	0.4681				0.1206		0.5139
XMg	0.3141				0.3982		0.4666
XCa	0.1833				0.4793		0.0106
XHn	0.0145				0.0019		0.0089
An						31.3	
Ab						65.7	
0.						2.0	
Mg N	•. 39.2	5.1	74.6	68.1	76.7	41.9	47.8
1	85DMSR-82, GT	2	85DMSR-82, IL	MENITE 3	850MSR-82,	810T	
4	850HSR-82, TI-AMPH	5	850MSR-82, PR	IN CPX 6	850MSR-82,	SP-CLOUDED PLAG	
7	850MSO-9, 0PX						

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	a STO DEVIATION PC	2	3	4	5	6	7
		- 6T	AMPH	PLAG	BIOT	OPX	CPX
\$102	51.19 an 0.56	38.19 ++ 0.40	40.38 +- 0.87	58.6 +- 2.5	35.4	52.49 +- 0.36	51.33 +- 0.93
1:02	0 21 += 0.30	0.03 += 0.03	2.57 +- 0.53	•	5.8	0.12 +- 0.03	0.52 +- 0.09
A120	1.82 += 0.17	21.53 += 0.33	12.91 ++ 0.42	25.8 +- 1.7	14.2	3.11 +- 0.42	4.37 +- 1.27
Cr20:	-	-	0.03 +- 0.04	-	-	-	-
Fe0	14.06 += 2.82	29.40 +- 1.09	18.32 +- 0.69	0.2 +- 0.4	20.0	19.60 +- 0.61	7.53 +- 2.34
Mn0	-	1.43 +- 0.17	0.10 +- 0.03	-	-	0.19 +- 0.03	0.09 +- 0.04
Maŭ	10.93 ++ 0.37	4.55 +- 0.52	8.55 +- 0.50	-	11.1	23.86 +- 0.61	13.47 +- 1.13
CaO	21.18 += 1.95	6.43 +- 0.36	11.56 +- 0.13	8.0 +- 2.0	-	0.49 +- 0.22	21.80 +- 3.38
Na20	0.60 += 0.36	-	1.59 +- 0.12	6.7 +- 0.9	0.6	•	0.72 +- 0.17
K20	-	-	1.75 +- 0.12	0.3 +- 0.2	9.8	-	-
C1	-	-	0.23 +- 0.03	-	-	-	-
F	•	-	0.05 +- 0.17	-	-	-	-
Total	99.99	101.56	98.04	99.5	96.9	99.86	99.83
Catio	108				:		
0	6.000	12.000	23.000	32.000	22.000	6.000	6.000
Si	1.953	2.977	6.141	10.522	5.381	1.929	1,905
Ti	0.006	0.002	0.294	-	0.663	0.003	0.015
A1	0.082	1.979	2.314	5.460	2.544	0.135	0.191
Cr	4 -	•	0.004	-	-	-	•
F#2	0.449	1,916	2.330	0.024 .	2.542	0.602	0.234
Mn	-	0.094	0.013	-	-	0.006	0.003
Ma	0.622	0.529	1.938	-	2.515	1,307	0.745
Ca	0.866	0.537	1.884	1.538	-	0.019	0.867
Na	0.044	-	0.469	2.327	0.177	-	0.052
ĸ	-	-	0.340	0.076	1,900	-	-
C1	-	-	0.059	-	-	-	-
F	-	•	0.024	-	•	-	-
Sum	4.022	8,033	15.810	19.950	15.723	4.001	4.011
Inter	-element ratios						0 1264
XFe	0.2317	0.6229				0.3114	0.1204
XMg	0.3211	0.1718				0.6/36	0.4031
XCa	0.4472	0.1745				. 0.0100	0.0015
XMn		0.0307				0.001i	0.0015
An				39.0			
Ab				59.0			
0r				2.0		60 F	76 1
Mg No	. 58.1	21.6	45.4	_	49.7	69.J	
1	850MSD-9, CPX	2.	850MSD-9, GT	3	1 850MS0-9, 11		
4	850MSD-9, PLAG	5	850MSD-9, 810T		5 800050-62C,	UFA	
7	850MS0-62C, CPX			- ·			

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MEAN & STO DEVIATION FOR PHASES FROM METAGABBROS

	1	2	3	4	5	· 6	7 191 A G
	GT	PLAG	AMPH	01.	OPX	CPX	FLAU 80 3 4- 1
Si02	39.75 +- 0.25	55.4 +- 2.6	41.2 +- 0.9	33.79 +- 0.44	51.22 +- 0.47	51.53 +- 0.45	33.5 += 1.
T102	0.04 +- 0.04	-	3.0 +- 0.7	- +- 0.01	•	0.34 += 0.07	
A1203	22.10 +- 0.36	27.6 +- 1.6	13.3 +- 0.9	- +- 0.01	1.79 +- 1.20	3.10 + 0.25	23.7 +- 13
Cr203	-	-	-	- +- 0.01	•	-	
FeO	22.46 +- 0.88	0.1 +- 0.4	11.6 +- 0.6	44.63 +- 0.75	25.45 +- 0.98	9.66 +- 1.21	0.2 - 0.
MnO	0.62 +- 0.12	-	-	0.32 +- 0.05	0.16 +- 0.30	0.14 +- 0.05	-
Maû	9.78 +- 0.68	•	11.9 +- 0.9	21.73 +- 0.38	20.61 +- 1.42	13.05 +- 0.13	
CaO	5.99 +- 0.12	10.4 +- 1.9	11.8 +- 0.5	0.01 +- 0.03	0.26 +- 0.11	21.21 +- 0.52	
Na20	•	5.5 +- 1.0	2.4 +- 0.8	- +- 0.01	-	0.87 +- 0.10	7.2 ** 1
K20	-	0.2 + 0.2	1.4 +- 0.2	-	-	•	0.2 += 0.
Total	100.74	99.3	96.6	100.48	99.49	99.90	100.1
Catione							
0	12.000	32.000	23.000	4.000	6.000	6.000	32.000
- 51	3 001	10.056	6.159	0.982	1.945	1.929	10.578
 T 1	0 007	-	0.341	-	-	0.010	0,001
A 1	1 967	5.812	2.341	-	0.080	0.137	5.412
C.e	-	-	•	-	-	-	0.001
Fa2	1.410	0.015	1.456	1.085	0.808	0.302	0.025
Mn	0.040	-	•	0.008	0.005	0.084	-
Ma	1,101	-	2.659	0.942	1.167	0.728	0.003
с.,	0 485	2.014	1.895	-	0.011	0.851	1.440
Na	-	1.978	0.696	-	-	0.063	2.474
r .	-	0.044	0.262	-	-	-	0.043
Sum	8.013	19.979	15.809	3.018	4.015	4.025	19.975
Inter-e	lement ratios						
XFe	0.4660				0.4060	0,1604	
XMg	0.3617				0.5861	0.3865	
xca	0.1592				0.0053	0.4513	
XMn	0.0130				0.0026	0.0024	
An		50.4					J0.4
Аb		48.5					84.J + 1
0-		1.1				_	
Mg No.	43.7		64.6	46.5	59.1	70.7	3.3
1 85	0MSD-62C. GT	2 -	850MSD-62, REX	T PLAG 3	850MSD-62C, T1	-амрн	
4 85	OMSO-68, OLIVINE	5	850MSD-68, 0PX	6	850HS0-68, CPX	C C C C C C C C C C C C C C C C C C C	
7 05	DHSD-FR. PLAG MO	AT	7	12			

	1	2	3	4	5	6	7
	GT	CPX	ILM	BIOT	AMPH	SPIN	PLAG
\$102	39,41 +- 0,31	50.63 +- 5.07	-	36.29 +- 0,96	40.76 +- 0.	19 0.07 +- 0.07	57.2 +- 0.4
T102	0.02 +- 0.05	1.28 +- 4.09	51.71 +- 0.	.54 6.64 +- 0.30	3.61 +- 0.	62 0.05 +- 0.04	-
A120	13 21.82 +- 0.32	3.14 +- 0.39	0.03 +- 0.	.01 14.43 +- 2.55	13.47 +- 0.	48 59.33 +- 0.21	26.9 +- 0.4
Cr20	3 - +- 0.01	0.01 +- 0.02	-	0.01 +- 0.02	0.01 +- 0.	03 0.01 +- 0.04	-
F+0	25.90 +- 0.42	9.94 +- 2.97	46.61 +- 0.	.32 15.00 +- 2.04	13.99 +- 0.	48 29.51 +- 0.34	- +- 0.1
MnQ	0.93 +- 0.09	0.14 +- 0.07	0.32 +- 0.	.06 0.01 +- 0.03	0.06 +- 0.	06 0.06 +- 0.03	-
MgQ	6.89 +- 0.39	12.91 +- 1.51	1.16 +- 0.	.01 14.14 +- 0.44	10.82 +- 0.	35 8.79 +- 0.06	-
CaO	6.43 +- 0.16	21.01 +- 2.09	-	0.06 +- 0.07	11.32 +- 0.	01 0.10 +- 0.03	9.0 +- 0.4
Na20	-	0.89 +- 0.16	-	0.22 +- 0.23	2.57 +- 0.	03 0.03	6.2 +- 0.6
K20	-	-	-	9.17 +- 0.54	1.56 +- 0.	04 -	0.2
Tota	1 100.40	99.95	99.83	95.97	98.17	97.95	99.5
_							
Cati	0N\$						
	12.000	6.000	3.000	22.000	23.000	4.000	10 201
31 Ti	2.973	1.901	-	5,400	8.077	0.002	-
11	0.001	0.036	0.982	0.743	0.405	1 955	5 609
AL	1.991	0.139	0.001	2.531	2,361	1.333	2.033
5.1	-	-	-	0.001	1 7//	n con	0.005
792 M-	1.6//	0.312	0.984	1.867 .	1. ( • •	0.630	0.005
ля М-	0.051	0.004	0.007	0.001	0.000	0.001	-
пg Г.	0.795	0.723	0.044	3.136	2.403	0.366	1 775
	0.533	0.845	-	0.010	1.000	0.003	3 175
ra v	-	0.065		0.063	0.143	0.002	0.046
К С	-	-	-	1.741	15 05/		19 960
2018	6.031	4.025	2.016	15.493	13.834	3.020	13.360
Inter	-element ratios						
XFe	0.5469	0.1656					
XHg	0.2593	0.3834					
XCa	0.1739	0.4486					
Xiin.	0.0199	0.0024			1		
An					(		43.8
Ab							55.0
0 <del>,</del>							1.2
Mg No	. 32.ż	69.8	4.2	62.7	58.0	34.7	
1	850MSD-68. GT	2	850MS0-68, PF	IM CPX 3	850MS0-68, 1		
4	850MS0-68, BIOT	5	850MSD-68. TI	L-AMPH S	850MS0-68, S	PINEL	
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7 850HSD-68, SP-CLOUDED PLAG

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MEAN & STO DEVIATION FOR PHASES FROM METAGABBROS

	1	2	3	4	5	5	7
	0L	OPX	CPX	AMPH	SYN	GT	CPX
510	2 34.53 +- 0.65	52.55 +- 0.6	8 52.75 +- 0.85	41.01 +- 1.76	40.42 +- 2.93	38.70 +- 4.44	51.52 +- 1.39
T10;	2 0.01 +- 0.04	0.03 +- 0.0	4 0.04 +- 0.06	0.51 +- 0.44	0.05 +- 0.16	0.04 +- 0.09	0.53 +- 0.63
A12	03 -	0.73 +- 0.2	3 3.07 +- 1.09	15.06 +- 2.04	19.40 +- 3.76	20.46 +- 7.31	3.20 +- 1.08
Cr2(	03 - +- 0.02	0.03 +- 0.0	5 0.01 +- 0.03	•	-	0.01 +- 0.04	0.01 +- 0.03
FeO	41.59 +- 2.13	23,18 +- 0.5	7 8.04 +- 0.97	11.94 +- 0.90	23.90 +- 3.00	24.48 +- 7.02	9.44 +- 1.52
MnÖ	0.29 +- 0.04	0.25 +- 0.03	3 0.10 +- 0.03	0.03 +- 0.07	0.73 +- 0.14	0.86 +- 0.45	0.15 +- 0.14
MgQ	24.55 +- 1.39	23.06 +- 0.6	1 13.38 +- 0.71	13.08 +- 1.02	7.34 +- 1.11	6.11 +- 3.60	12.39 +- 1.41
CaO	0.01 +- 0.02	0.38 +- 0.14	£ 20.44 +- 1.35	11.49 +- 0.39	8.90 +- 2.89	9.35 +- 5.54	21.41 +- 0.91
Na2(	<b>-</b>	- +- 0.0	2 1.75 +- 0.70	2.67 +- 0.54	0.32 +- 0.38	0.07 +- 0.44	1.31 +- 0.45
K20	-	-	- +- 0.01	1.68 +- 0.97	-	- +- 0.01	-
Tota	l 100.98	100.21	99.58	97.47	101.06	100.08	99.96
Cati	ons						
0	4.000	6.000	6.000	23.000	12,000	12.000	6.000
51	0.982	1.960	1.962	5.089	3.097	3.015	1.929
Ti	-	0.001	0.001	0.057	0.003	0.002	0.015
A1	•	0.032	0.135	2.636	1.752	1.079	0.141
CP	-	0.001	-	-	-	0.001	•
Fe2	0.989	0.723	0.250	1.483	1.532	1,595	0.296
lln	0.007	0.008	0.003	0.004	0.047	0.057	0.005
ng	1.040	1.282	0.742	2.695	0.838	0,710	0.692
Ca	-	0.015	0.814	1.828	0.731	0,780	0.059
Na	-	-	0.126	0.769	0.048	0.011	0.095
ĸ	-	-	-	0.318	-	-	•
Sum	3.018	4.022	4.033	16.079	9.049	8.049	4.032
Inter	r-element ratios						
XFe		0.3565	0.1382			0.5077	0.1597
XHg		0.6321	0.4099			0.2258	0.3736
XCa		0.0075	0.4501			0.2484	0.4641
XMn		0.0039	0.0017			0.0181	0.0026
rig Na	51.3	63.9	74.8	66.1	35.4	30.8	70.1
1	850MSK-2, OLIVINE	2	850MSK-2, OPX	t	850HSK-2, CPX		
4	BSDHSK-2, PALE AMP	4 S	850MSK-2, GT SYM	1 6	850MSK-2, GT		
1	850MSK-2, PRIM CPX						

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	1	2	Э	4	5	6	7
	TLM	BIOT	AMPH	PLAG	OL	OPX	CPX
\$102	0.01 +- 0.04	36.62 +- 0.99	39.95 +~ 0.31	56.31 +- 4.06	36.04 +- 0.57	53.61 +- 0.40	53.71 +- 0.95
T102	51.21 +- 0.84	5.91 +- 1.07	3,18 +~ 0,18	0.08 +- 0.15	0.01 +- 0.04	0.05 +- 0.02	0.11 +- 0.08
A120	0.02 +- 0.03	14.34 +- 0.53	13.86 +- 1.16	26.52 +- 2.85	-	0.95 +- 0.05	4.24 +- 2.05
Cr20	3 0.01 +- 0.02	0.06 +- 0.13	0.08 +~ 0.12	-	-	-	-
F+O	47.18 +- 1.19	15.04 +- 4.79	14.65 +~ 0.29	1.75 +- 1.78	37.62 +- 2.56	20.59 +- 1.07	7.01 +- 1.18
MnO	0.34 +- 0.06	0.01 +- 0.03	0.06 +- 0.05	-	0.25 +- 0.20	0.16 +- 0.05	0.11 +- 0.07
MgQ	0.86 +- 0.63	14.39 +- 4.08	10.16 +- 0.63	0.59 +- 0.80	27.20 +- 2.23	23.98 +- 0.46	12.38 +- 1.12
CaO	-	-	11.18 +- D.50	6.74 +- 2.07	0.02 +- 0.03	0.44 +- 0.20	19.86 +- 1.93
Na20	0.01 +- 0.02	0.37 +- 0.10	2.66 +- 0.54	7.24 +- 1.16	-	0.01 +- 0.04	2.38 +- 1.20
K20	-	9.61 +- 0.66	1.72 +- 0.81	0.40 +- 0.52	•	-	-
Tota	1 99.64	96.35	97.50	99.71	101.14	99.79	99.80
Cati	Das						
0	3.000	22.000	23.000	32.000	4.000	6.000	6.000
SL	•	5.441	6.030	10.208	0.999	1.979	1.976
Τi	0.978	0.660	0.361	8.011	-	0.001	0.003
AL	0.001	2.511	2.466	5.667	-	0.041	0.194
Cr	4 -	0.007	0.010	•	•	-	-
F+2	1.002	1.869	1.849	0.265	0.972	0.636	0.216
Ma	0.007	0.001	0.008	- `	0.006	0.005	0.003
Mg	0.033	3.187	2.286	0.159	1.124	1.319	0.679
Ca	-	-	1.808	1.309	0.001	0.017	0.793
Na	-	0.107	0.778	2.545	-	0.001	0.170 ,
ĸ	-	1.821	0.331 .	0.117	•	-	- · ·
Sum	2.022	15.604	15.927	20.276	3.001	4.000	4.014
Inter	-element ratios						
XFe						0.3214	0.1283
XMg	•					0.6672	0.4039
XCa	•					0.0089	0.4657
XMn						0.0025	0.0020
An '				33.0			
Ab -				64.2			
0r				2.8			
rig Ne	. 3.1"	63.0	55.3	37.5	56.3	67.5	19-2
1	85DMSK-2, ILMENITE	2	85DMSK-2, BIOT	3	850MSK-2, TI-A	1911	
4	850HSK-2, SP-CLOUD	ED PLAG S	850MSK-10, OLIVI	INE G	850MSK-10, OPX		
7	850MSK-10, CPX						

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MEAN & STD DEVIATION FOR PHASES FROM METAGABBROS

	1	2	3	4	5	6	7
	AMPH	SYM	SYM	GT	CPX	ILM	910T
SiQ	2 41.6 +- 2.5	43.87 +- 3.35	5 42.46 +- 1.86	39.04 +- 0.73	50.02 +- 3.	17 0.4 +- 0.2	36,9 +- 0.8
TLO	2 2.4 +- 0.8	0.27 +- 0.08	0.10 +- 0.14	-	1.51 +- 0.	.34 . 53.2 +- 0.4	7.1 +- 3.0
A12	03. 13.7 +- 2.0	16.26 +- 3.40	17.87 +- 2.24	22.07 +- 1.27	4.32 +- 1.	.73 -	14.6 +- 0.8
FeQ	11.4 +- 1.4	9.60 +- 2.31	19.80 +- 1.59	23.02 +- 1.69	9.32 +- 1.	50 47.0 +- 0.6	12.6'+- 2.7
HnŪ	0.1 +- 0.3	0.08 +- 0.04	0.50 +- 0.11	0.62 +- 0.21	0.12 +- 0.	0.1 +- 0.3	-
MgQ	10.8 +- 0.8	11.15 +- 2.10	8.95 +- 0.88	7.16 +- 1.07	12.20 +- 0.	54 1.5 +- 0.3	14.4 +- 2.8
CaQ	12.8 +- 2.6	16.82 +- 2.76	10.29 +- 2.06	8.75 +- 1.96	20.88 +- 0.	96 -	•
Na2(	2.8 +- 0.8	2.06 +- 1.35	0.55 +- 0.30	•	1.53 +- 0.	04 -	0.2 +- 0.6
K2Q	1.5 +- 0.5	0.06 +- 0.24	0.01 +- 0.03	-	•	•	9.9 +- 0.3
Teta	1 97.1	100.17	100.53	100.66	99,90	102.2	95.8
Cati	lons						
0	23.000	23.000	12.000	12.000	6.000	3.000	22.000
Sı	6.205	6.241	3.214	2,985	1.877	0.011	5.453
Τi	0.274	0.029	0.006	-	0.043	0.980	0.790
Al	2,409	2.727	1,594	1,989	0.191	•	2.542
F+2	1.420	1,142	1.253	1,472	0.293	0.962	1.559
Mn	0.008	0.010	0.032	0.040	0.004	0.002	•
Mg	2.410	2.365	1.010	0.816	0.682	0.055	3.171
Ca	2.049	2.564	0.834	0,717	0.840	-	-
Na	0.798	0.568	0.081	-	0.111	-	0.069
ĸ	0,289	0.011	0.001	-	-	-	1.874
Sum	15.861	15.656	8.025	8.020	4.040	2.009	15.450
Inte	r-element ratios						
XFe				0.4834	0.1609		
XMg				0.2680	0.3753		
XCa				0.2354	0.4617		
XHn				0.0132	0.0021		
Mg Ni	•. 62.9	67.4	44.6	35.7	70.0	5.4	67.0
1	850HSK-10, PALE A	мрн 2	850MSK-10, AMPH	SYM D	85DMSK-10, G	IT SYM	
4	050MSK-10, GT	5	850MSK-10, PRIM	CPX 6	850MSK-10, I	LMENITE	

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7 850MSK-10, 8107

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	1 Амры	2 501 M	3	4	5	8	7
S102	43.0 +- 3.8	-	55 14 Am 3 20	34 55 4- 0 73	57 66 4- 0 41	57 75 A. 0 70	317 41 DE 1. 4 40
T102	3.8 += 2.0	0.2 0.4	6 13 4- 0 13		0.05 += 0.05		0.00 ++ 1.48
A1203	12.4 +- 2.4	57 5 4- 1 4	27 16 44 1 84	-	1 26 44 0 31	3 61 4- 0 50	19 55 1 40
Cr203	-	2.7 += 0.2	-	-		5.61 +- 0.50	10.33 44 1.40
FeD	10.7 += 2.8	29.2 ** 0.5	2 11	42 34 An 4 06	23 60 44 2 09	9 07 4- 1 77	27 80 44 1 81
MnO	-	-	-	0 30 += 0 13	0.74 += 0.09	0 12 4- 0 05	0 71 4- 0 10
MaQ	10.5	9.4 - 12	1 79 1 58	22 72 4- 1 36	21 46 4- 1 78	12 18 4- 0.03	7 75 4- 0 91
CaO	13.8 ++ 3.5	-	5 43 4- 1 21	0 01 44 0 02	0.51 += 0.75		1.13 V- 0.33
Na20	3.1 += 0.3	0.8 - 0.8	7 20 4- 0 56		0.07 += 0.25	1 69 4- 0 74	0.82 - 0.18
K20	1.4 += 0.7	0.4 +- 0.6	0 45 - 0 15	-	-	1.00 - 0.24	0.26 ++ 0.13
Total	98.5	99.9	100.01	100.03	99.80	99.46	100.52
Cation							
0	23.000	4.000	32.000	4.000	6.000	6.000	12.000
SL	6.306	•	10.011	0.998	1.973	1.957	3,151
Ti	0.420	0.005	0.018	-	0.001	0.004	0.005
A1	2.137	1.876	5.812	-	0.056	0.159	1.679
Cr	, -	0.059	•	-	-	-	-
F+2	1.314	0.679	0.472	1.020	0.740	0.284	1,509
Ma	-	•	-	0.007	0.008	0.004	0.046
Mg	2.298	0.388	0.376	0.976	1.199	0.679	0.887
Ca	2.163	-	1,056	-	0.020	0.813	0.709
Na	0.803	0.041	2.535	•	0.001	0.122	0,039
ĸ	0.253	-	0.104 .	-	-	-	
Sum	15.773	3.048	20,385	3.002	3.998	4.021	8.024
Inter-e	lement ratios						
XFe .					0.3761	0.1593	
XMg	•				0.6096	0.3814	
XCa	•				0.0104	0.4571	
XMn					0.0039	0.0021	**
An 1			28.6				
Ab			68.6				
0 <del>r</del>			2.8				
Mg No.	63.9	36.4	44,3	48.9	61.8	70.5	37.0
1 850 4 850 7 850	DMSK-10, TI AMPH DM-230, OLIVINE DM-230, GT SYM	2 5	850MSK-10, SPINE 850M-230, OPX	L AOJ ILN 3 B	850MSK-10, SP-1 850M-230, CPX	LOUDED PLAG	

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MEAN & STD DEVIATION FOR PHASES FROM METAGABBROS

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	1	2	3	4	5	6	7
	GT	ILM	AMPH	CPX	PLAG	PLAG	SPIN
510	2 38.99 +- 0.57	0.3 +- 0.1	40.5 ++ 0.5	51.78 +- 1.2	0 55.66 +- 2.	63 59.3 +- 1.9	0.8 +- 0.9
TIC	2 0.06 +- 0.01	50.5 +- 1.3	4.0 +- 0.3	0.40 +- 0.0	4    0.09 +- 0.	04 -	•
A12	03 21.61 +- 0.27	-	12.8 +- 0.7	3.68 +- 1.5	6 27.09 +- 1.	39 25.0 +- 0.6	55.7 +- 0.3
Fe0	24.99 +- 1.38	47.6 +- 0.8	14.3 +- 0.6	9.19 +- 1.4	2.60 +- 1.	23 -	34.3*+- 1.6
MnO	0.81 +- 0.20	-	-	0.11 +- 0.0	6     0.01 += 0.	03 -	•
Mgû	6.60 +- 1.29	1.5 +- 0.1	10.4 +- 0.2	11.75 +- 0.3	Q.57 +- 0.	22 -	7,4 += 0.1
CaO	7.43 +- 2.06	-	10.9 +- 0.4	20.60 +- 1.0	3 6.14 +- 0.	43 7.3 +- 0.9	0.1 +- 0.2
Na20		-	3.3 +- 0.2	1.67 +- 0.13	7.35 +- 0.	55 7.0 +- 0.7	0.2 +- 0.6
K20	-	-	1.2 +- 0.2	•	0.45 +- 0.	07 0.4 +- 0.2	•
Tati	1 100.49	100.1	97.4	99.18	99.96	99.0	98.4
Cati	ions						
۵	12.000	3.000	23.000	6,000	32.000	32.000	4.000
Si	3.006	0.009	5.095	1,946	10.090	10.676	0.023
Τi	0.003	0.960	0.457	0.011	0.012	-	•
A1	1.964	-	2.264	0.163	5.793	5.314	1.675
Fe2	1.611	1.005	1.802	0.289	0.395	-	0.820
Mn	0.053	•	-	0.004	0.002	-	-
Mg	0.759	0.058	2.336	0.658	0.154	-	0.314
Ca	0.614	-	1.765	0.830	1.194	1.409	0.004
Na	-	-	0.964	0.122	2.586	2.438	0.009
ĸ	-	-	0.231	•	0.104	0.099	•
Sum	B.009	2.032	15.914	4.022	20.338	19.935	3.044
Inte	r-element ratios						
XFe	0.5306			0.1623			
XMg	0.2498			0.3690			
XCa	0.2021			0.4660			
XMn	0.0174			0.0020			
An					30.7	35.7	
A6					66.8	61.8	
Qr					2.7	2.5	
Ng Ni	•. 32.0	5.5	56.5	69.5	28.1		27.7
1	850M-230, GT	2	BSDH-230, ILHE	NITE 3	850M-230, T1	-AMPH	
4	850M-230, PAIN CPX	5	850M-230, PLAG	LATH(SCAN) 6	850H-230, PL	AG ADJ SPIN	
7	850M-230, SPINEL						

MEAN & STO DEVIATION FOR PHASES FROM GRANULITES

	1	2	3	4	5	6	7
	CPX	OPX	GT	PLAG	ILM	AMPH	8107
510	2 51.25 +- 0.62	50.11 +- 0.42	38.05 +- 1.05	60.3 +- 1.7	0.4	41.5 +- 0.5	36.8 +- 0.1
T10	2 0.21 +- 0.08	-	0.05 +- 0.04	- ·	53.0 +- 1.0	2.3 +- 0.3	5.3 +- 0.1
A12	03 1.84 +- 0.54	0.62 +- 0.28	21.37 +- 0.45	24.6 +- 0.5	-	12.3 +- 0.2	14.2
Fe0	12.94 +- 0.84	32.80 +- 0.66	27.22 +- 4.14	-	48.2 +- 0.4	18.9 +- D.G	19.2 +- 2.0
Mnû	0.13 +- 0.03	0.31 +- 0.07	0.79 +- 0.30	-	0.3 +- 0.1	-	•
NgŪ	10.92 +- 0.47	15.16 +- 0.45	3.72 +- 0.47	-	0.6 +- 0.6	8.3 +- 0.2	11.4 +- 1.0
CaO	21.94 +- 0.81	0.56 +- 0.06	9.44 +- 3.17	<b>5.8</b> +- 1.0	-	11.6 +- 0.3	-
Na2	0.43 +- 0.09	-	-	7.3 +- 0.5	-	1.6 +- 0.3	0.6 +- 0.1
K20	•	-	-	0.4 +- 0.1	•	1.7 +- 0.1	9.9 +- 0.1
Tati	1 99.66	99.56	100.64	99.5	102.5	98.2	97.3
Cat	lona						
0	6.000	6.000	12.000	32.000	3.000	23.000	22.000
S١	1.956	1.975	2.983	10.788	0.010	6.306	5.521
T1	0.006	-	0.003	•	0.980	0.259	0.604
A1	0.003	0.029	1.975	5.199	-	2.196	2.514
FeZ	0.413	1.081	1.785	-	0.991	2.396	2.412
Mo	Q.004	0.010	0.052	•	0.007	• •	-
Mg	0.621	0.891	0.435	•	0.022	1.885	2.542
Ca	0.897	0.024	0.793	1.312	•	1.892	-
Na	0.032	-	-	2.527	-	0.480	0.160
κ	-	-	-	0.100	-	0.324	1.888
Sum	4.012	4.010	.026	19.926	2.010	15.739	15.642
Inte	r-element ratios		-				
XFe	0.2134	0.5390	0.5823				
XHg	0.3210	0.4440	0.1418				
XCa	0.4635	0.0118	0.2587				
XMn	.0.0022	0.0052	0.0171				
An	•			33.3			
ÅЬ				64.1			
Ûr	*			2.6			
Mg N	o. 60.1	45.2	19.6		2.2	44.0	51.3
1	850MS-2A, CPX	2	85DMS-2A, OPX	3	850MS-24, GARN	ET	
4	850MS-2A, PLAG	5	850HS-2A, ILM	6	850HS-2A, AHPH		
7	85DMS-2A, BIOT			-			

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MEAN & STD DEVIATION FOR PHASES FROM GRANULITES

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		1 2		3	4	5	6	7
	CI	PX OP	x	PLAG	АНРН	GT	CPX	PLAG
\$10	2 51.35	- 0.74 51.45 +	- 0.46	55.9 +- 0.9	42.5 +- 1.3	37.98 +- 0.26	51.44 +- 0.64	59.9 +- 0.7
T10	2 0.35 -	- 0.04 0.06 +	- 0.05	-	2.0 +- 0.5	0.08 +- 0.04	0.17 +- 0.04	-
A12	03 3.07	- 0.27 1.80 +	- 0.52	28.1 +- 1.0	12.4 +- 1.2	20.61 +- 0.29	1.82 +- 0.13	24.3 +- 0.8
Fe0	9.74	- 0.55 26.51 +	- 0.55	-	15.0 +- 0.7	29.52 +- 2.06	14.47 +- 0.55	-
MnO	0.26	- 0.05 0.65 +	- 0.05	-	<b>.</b> .	2.76 +- 2.57	0.54 +- 0.31	<b>-</b> ·
MgQ	12.12 +	- 0.32 19.09 +	- 0.55	-	11.3 +- 0.8	2.95 +- 0.34	10.03 +- 0.21	-
CaO	22.25 +	- 0.36 0.42 +	- 0.07	10.6 +- 0.6	11.8 +- 0.4	7.41 +- 0.53	21.48 +- 0.29	6.3 +- 0.5
Na2i	0 0.62 +	- 0.07 -		5.3 +- 0.5	1.9 +- 0.2	-	0.66 +- 0.10	7.6 +- 0.4
K20	-	-		-	1.1 +- 0.1	•	•	•
Tota	1 99.76	99.98		99.9	98.1	101.31	100.61	98.1
Cati	lons							
0	6.000	6.000		32.000	23.000	12,000	6.000	32.000
Si	1.931	1.956		10.044	6.332	3.001	1.959	10.835
Τŝ	0.010	0.002		-	0.225	0.005	0.005	-
AL	0.136	0.081		5.958	2.180	1.919	0.082	5,180
Fe2	0.306	0.843		•	1.866	1.951	0.461	· ·
Mn	0.008	0.021		-	-	0.185	0.017	•
Hg	0.680	1.082		-	2.493	0.347	0.570	-
Ca	0.897	0.017		2.047	1.093	0.627	0.677	1.221
Na	0.045	-		1.054	0.536	-	0.049	2.677
ĸ	-	-		-	0.214	-	•	-
Sum	4.013	4.002		19.904	15.728	8.035	4.019	19.913
Inte	r-element rat	tios						
XFe	0.1620	0.4294				0.6272	0.2395	
XHg	0.3594	0.5512				0.1117	0.2959	
XCa	0.4742	0.0087				0.2017	0.4555	
XMn	0.0044	0.0107				0.0594	0.0091	
An				52.5				31.3
Ab L				47.5				68.7
Mg No	o. 68.9	56.2			57.2	15.1	55.3	
1	840MSA-1A, C	PX	2	840MSA-1A, OPX	3	840HSA-1A, PLAG	•	
4	840HSA-1A, R	ETROGRSSIVE AMPH	5	84DMSA-5A, GT	6	840MSA-SA, CPX		

7 84DHSA-5A, PLAG

MEAN & STO DEVIATION FOR PHASES FROM GRANULITES

		1	z	:	3		4		5	6		7
	(	6T	GT		OPX		CPX	1	PLAG	AMP	н	61
SiO	2 38.55	+- 0.43	38.62 +	- 0.59	50.49 +-	1.25	50.68 +-	0.67	53.8 +- 1	1.4 41.8 +-	0.6 38.62	: +- 0.53
T102	2 0.07	+- 0.05	-		0.07 +-	0.04	0.26 +-	0.04	-	2.0 +-	0.1 0.07	' +- 0.03
A12	03 21.23	+- 0.27	21.35 +	- 0.25	1.57 +-	0.61	2.95 +-	0.39	29.1 +- 1	1.0 12.8 +-	1.0 20.76	i +- 0,24
FeO	25.51	+- 8.45	27.96 +	- 1.09	29.20 +-	1.45	10.85 +-	1.98	-	17.4 +-	0.6 27.73	+- 0.80
MnO	0.91	+- 0.14	1.29 +	- 0.16	0.52 +-	0.20	0.19 +-	0.08	-	-	2.46	i +- 0.23
MgO	4.75	+- 0.49	4.91 +	- 0.55	17.49 +-	1.23	11.85 +-	0.64	-	9.3 +-	0.3 4.45	+- 0.45
CaO	9.97	+- 0.78	7.35 +	- 0.52	0.54 +-	0.29	22.38 +-	0.58	11.9 +- 0	0.9 11.4 +-	0.4 7.51	+- 0.28
Na20	) –		-		-		0.56 +-	0.06	4.7 +- (	0.5 1.6 +-	0.1 -	
K20	-		-		-		-		-	1.5 +-	0.1 -	
Tota	1 100.99		101.48		99.88		99.73		99.5	97.9	101.60	ļ.
Cati	lons											
0	12.000		12.000		6.000		6.000		32.000	23,000	12.000	l
Si	2.992		2.997		1.950		1.920		9.759	6,311	3.009	l
Ti	0.004		-		0.002		0.007		-	0,221	0.004	
A1	1.942		1.953		0.071		0.132		6.225	2,269	1.907	
Fe2	1.656		1.814		0.943		0.344		-	2.197	1.807	
Mn	4 0.060		0.085		0.017		0.006		-	-	0.162	
Hg	0.550		0.568		1.007		0.669.		-	2.093	0.517	
Ca	0.829		0.611		0.022		0.908		2.316	1.852	0.627	
Na	-		-		-		0.041		1.654	0.483	-	
ĸ	-		-		-		•			0,299	-	
Sum	8.033		8.027		4.012		4.028		19.955	15.724	8.033	
Inte	r-element r	atics										
XFe	0.5351	(	0.5894		0.4741	(	0.1785				0.5804	
XHg	0.1776	(	0.1845		0.5061	(	0.3471				0.1660	
XCa	0.2679	C	3.1985		0.0112	(	3.4712				0.2014	
XMn	0.0193	(	1.0275		0.0086		1.0032				0.0522	
Ån	٠								58.3			
Ab,									41.7	•		
Mg No	. <u>24.9</u>		23.0		51.6		66.0			49.8	22.2	
1	840HSA-44,	HIGH-Ca C	ST(C) .	2	840MSA-44,	GT (R 8	k Nr R)	3	840MSA-44,	OPX		
4	840MSA-44,	CPX		5	840MSA-44,			6	B4DMSA-44.	RETROGRESSIVE	апрн	
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7 840MSA-948, GARNET

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MEAN & STO DEVIATION FOR PHASES FROM GRANULITES

			-	7	4	5	6	7
	1 204		2 191.10	AMPH	ST	OPX	MEAN	KSPR
\$102	50.61 Am	1.26	56.9 +- 1.2	40.5 +- 2	.8 38.6 +~ 0	.8 50.6 +- 0.	.7 61.0 +- 1.0	64.7 +- 0.8
T+02	0.28	0.06	-	2.4 +- 0	.6 -	-	-	-
4120	3 2.85	0.65	27.0 +- 0.7	11.9 +- 0	.7 21.3 +- 0	.2 2.2 +- 0.	.5 24.7 +- 0.6	18.4 +- 0.4
Fe0	12.69	1 51	_	18.7 +- 1	.0 32.6 +- 1	.1 30.6 +- 0.	.7 -	-
MoO	0.39	0 11	-	•	-	-	-	-
Maū	11 06 4-	0.75	-	8.6 +- O	.7 5.4 +- (	),4 17.3 +- 0.	.5 -	
C > 0	21 29 4-	1 92	9.4 - 0.6	12.2 +- 3	.0 3.4 +- 0	1.5 0.3 +- 0.	.2 6.2 +- 3.4	-
N-20	0.62 +-	0.05	6 0 4= 0.6	1.6 +- 0	.2 -	-	7.4 +- 0.6	0.7 +- 0.5
N20	0.03 +-	0.03	0.2 += 0.1	1.9 += 0	.2 •	-	-	15.9 +- 1.5
Tota	- 1 99.89		99.5	97.9	101.3	101.0	99.2	99.6
Cati	07.5							
đ	6.000	32	.000	23.000	12.000	6.000	32,000	J2.000
Si	1.926	10	.257	6.207	3.010	1.937	10,876	11,981
TL	0.008		-	0.277	-	-	-	-
A1	0,128		5.734	2.153	1.962	0.099	5,191	4.UZB
Fe2	0.404		-	2.401	2.126	0,980	-	-
Mn	0.013		-	-	-	-	-	:
Mg	0.628		•	1.960	0.620	0.965	-	-
Ca .	0.872	1	.806	2.008	0.284	0.013	1,100	-
Na	0.046	2	. 104	0.490	-	-	2,564	0.244
ĸ		0	.055	0.375	•	•	-	3,133
Sum	4.025	19	, 956	15.872	8.009	4.014	19.810	20,006
Inte	r-element rati							
XFe	0.2108				0.6997	U, 4933		
XMg	0.3275				0.2068	0,4300 0,4300		
XCa	0.4551				0.0936	0.0000		
XHa	0.0066							
An			45.5					6.1
Ab			53.1					97.9
0r			1.4			<b>e</b> 0.1		
Mg N	o. 60.8			44.9	22.8	50.1		
1	840MSA-948. C	PX	2	840MSA-948,	PLAG	3 840MSA-948.	RETROGRESSIVE AMP	H
4	850HSA-166. G	ARNET	5	850MSA-166.	OPX	6 850MSA-166,	PLAG	
7	850MSA-168, K	-FSPA						

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MEAN & STO DEVIATION FOR PHASES FROM GRANULITES

	•	2	3	4	5	6	7
	BT	GT	CPX	OPX	PLAG	CPX	OPX
\$102	36.6 +- 1.0	39.32 +- 0.76	51.58 +- 1.5	53 51.69 +- 0.43	59.4 +- 1.3	51.62 +- 1.27	50.41 +- 0.67
T102	5.2 +- 2.0	•	0.26 +- 0.0	0.05 +- 0.01	-	0.17 +- 0.11	0.08 +- 0.06
A1203	15.1 +- 1.3	21.39 +- 0.35	2.76 +- 0.	71 1.30 +- 0.27	25.5 +- 1.0	1.64 +- 0.48	0.70 +- 0.25
F+0	17.7 +- 4.3	24.90 +- 1.95	10.07 +- 1.4	45 25.06 +- 0.74	-	15.12 +- 1.80	35.98 +- 0.25
Mot	-	1.91 +- 1.14	0.26 +- 0.4	07 0.74 +- 0.07	-	0.24 +- 0.06	0.56 +- 0.09
MaD	11.6 +- 3.4	5.44 +- 0.39	12.31 +- 0.4	83 19.97 +- 0.54	-	9.90 +- 0.77	13.52 +- 0.28
CaO	-	8.55 +- 2.74	21.87 +- 0.	90 0.42 +- 0.04	7.6 +- 0.9	21.74 +- 1.17	0.59 +- 0.04
Na20	-	-	0.75 +- 0.1	10 -	7.0 +- 0.4	0.57 +- 0.14	•
K20	9.7 += 0.2	-	-	-	0.5 +- 0.1	•	-
Total	95.9	101.51	99.87	99.23	99.8	101.08	101.84
<b>e</b>							
Lation	32 000	12 000	s 000	6.000	32.000	S.000	6.000
с. С.	22.000	3 021	1.979	1,968	10.619	1.961	1.970
31 T4	5.515	3.021	0.007	0.001	-	0.005	0.002
	3 683	1 937	0.122	0.058	5.368	0.073	0.032
5.2	2.003	1 600	0.317	0.798	-	0.480	1.176
Ha	2.233	0.126	0.008	0.024	-	0.008	0.019
Ha	2 600	0.627	0.690	1.134	-	0.565	0.788
rs rs	2.000	0.704	0.881	0.017	1.449	0.885	0.025
N.	-	-	0.055	-	2.414	0.042	-
¥	- 1 868	-	-	-	0.107	-	•
Sum	15.488	8.010	4.020	4.001 '	19.957	4.019	4.011
			-				
Inter-	element ratios		0 1670	0.4046		0.2478	0.5860
AF		0.3244	0.1010	0.5746		0.2916	0.3925
Xng		0.2042	0.5653	0.0087		0.4566	0.0123
XLA VM		0.2307	0.4041	0.0121		0.0040	0.0092
X710		0.0407	0.0044	0.0121	36.5		
An					60.8		
AD .					2.7		
Ur Mg No.	53.8	28.0	68.5	58.7		54.1	40.1
-		•	AF2461 480 1	CARNET 3	850MSH-100, C	PX	
18	SOMSA-166, BIOT	2	850054-100,		850MSH-1084.	CPX	
4 E	SOMSH-100, OPX	2	820024-1001				

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7 850MSH-108A, 0PX

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MEAN & STO DEVIATION FOR PHASES FROM GRANULITES

		•	•	4	· 5	6	7
	1	4	5010	AMPH	CPX	GT	PLAG
	GT	PLAG	05 7 A- 0 P	40.6 +- 0.9	50.27 +- 0.62	37.62 +- 0.25	64,3 +- 1.1
5102	· 38.17 +- 0.09	60.8 +- 0.6	33.7 +- 0.8	2 0 += 0.1	0.15 +- 0.06	0.07 +- 0.03	-
T102	•	-	5,4 +- 0.5	11 6 40 0.5	0.88 +- 0.39	20.45 +- 0.31	22.4 +- 0.8
A1203	21.03 +- 0.26	24,3 +- 0.7	13.3 +- 0.8	20 5 4= 0.8	22.07 +- 0.92	32.73 +- 0.36	-
Feū	30.11 +- 0.81	•	22.6 +- U.J	20.5 ** 0.0	0.40 +- 0.06	2.13 +- 0.16	- ·
MnÖ	1.61 +- 0.08	•	-	7 5 4- 0 3	5.58 +- 0.50	1.08 +- 0.14	-
MgQ	2.96 +- 0.40	-	8.8 +- 0.9	1.3 +- 0.5	20.55 +- 1.17	7.24 +- 0.24	3.8 +- 0.3
CaO	7.25 +- 0.75	6.1 +- 0.2	•		0 48 ++ 0.39	•	9.0 +- 0.4
Na2O	-	7.7 +- 0.5	•	1.8 +- 0.4	-	-	0.2 +- 0.2
K20	-	0.3 +- 0.2	9.6 +- 0.5	1.7 +- 0.1	100 78	101.32	99.7
Total	101.13	99.3	95.6	96.0	100.30		
Catto							
0	12 800	32.000	22.000	23.000	6.000	12.000	32.000
S.	3 009	10.873	5.550	6.337	1,985	3,009	11.334
T 4	3.003		0.631	0.241	0.004	0.004	
A1	1 954	5.131	2.470	2.097	0.041	1.928	4.6/1
F	1 985	-	2.933	2.674	0.729	2,189	•
Ma	0 107	-	•	-	0.013	0.144	-
Ha	0.349	-	2.044	1.741	0.329	0,129	-
Га	0.540	1.177	-	1.862	0.870	0,620	0.725
Na	0.012	2.685	-	0.499	0.037	-	1,0/3
*	-	0.078	1.912	0.345	-	•	0.047
Sum	8.015	19.943	15.540	15.795	4,008	8.023	13.011
•	• • • •						
Inter	-element ratios				0.3757	0.7102	
***	0.6502				0.1693	0.0418	
Xrig	0.1139				0,4482	0.2013	
XLa	0.2006				0.0069	0.0468	
X00	0.0352						18.9
An		29.9					79.5
64		68.2					1.2
Ur Ma H-	14.9	2.0	41.1	39.4	31.1	5.6	
			****				
1	BEDMSHIDBA, GARNET	r 2	85DMSH-108A, P	LAG	850MSH-108A, 1	SIUT ANET	
4	850HSH-108A. AMPH	5	850MSR-27, CPX	; í			

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4 850HSH-108A, AMPH 7 850HSR-27, PLAG

HEAN & STO DEVIATION FOR PHASES FROM HOST GNEISSES

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	1	2	Э	4	5	8	7
	GT	81	PLAG	PLAG	GT	91	AMPH
S102	38.16 +- 0.53	35.69 +- 0.37	62.4 +- 1,3	59.4 +- 1.0	37.7 +- 0.6	35.5 +- 1.0	40.0 +- 0.3
T102	0.05 +- 0.29	4.63 +- 0.47	-		- +- 0.1	4.9 +- 0.6	1.7 +- 0.1
A120	3 21.30 +- 0.25	16.75 +- 0.83	23.1 +~ 0.9	24.9 +- 0.5	20.7 +- 0.5	14.5 +- 1.0	12.3 +- 0.3
Cr20	3 0.02 +- 0.04	- +- 0.03	-	-	-	-	-
F.Q	34.72 +- 1.65	18.37 +- 0.69	-	- +- 0.3	28.7 +- 1.4	22.9 +- 2.0	21.4 +- 1.6
MnO	0.89 +- 0.53	-	-	-	4.1 +- 1.1	0.1 +- 0.3	0.2 +~ 0.3
MgO	5.16 +- 0.78	10.51 +- 0.63	-	-	2.6 +- 0.7	8.6 +- 1.4	7.3 +- 0.9
CaO	1.16 +- 0.53	-	4.5 +~ 0.6	6.9 +- 0.4	6.9 +- O.B	0.1 +- 0.4	11.4 +- 0.3
N#20	-	0.12 +- 0.03	8.6 +~ 0.2	7.4 +- 0.3	-	0.2 +- 0.8	1.5 +~ 0.5
X20	-	9.88 +- 0.36	0.4 +~ 0.5	0.2 +- 0.3	-	9.4 +- 0.7	1.5 +~ 0.3
Tota	1 101.46	95.95	99.0	98.9	100.6	96.1	98.2
Cati	909						
0	12.000	22.000	32.000	32.000	12.000	22.000	23.000
Si	2.937	5.400	11,151	10.709	2,999	5,491	0.404
T4	0.003	0.527	-	•	0.001	0.574	2 220
AL .	1.972	2.987	4.870	5.290	1.944	2.540	2.2.5
Cr 👘	- 10.001	-	-	•	-	-	2 750
F#2	2.280	2.324	-	0.006	1.911	2.333	0 030
Mn	0.059	-	-		0.275	1.070	1 640
Hg	0.604	2.370	-	-	0.308	0.022	1.875
Ca	0.090	•	0.865	1.326	4.591	0.022	0.462
Na	-	0.035	2.972	2.582	-	1 849	0.204
ĸ	-	1.907	0.097 -	0.048	9 029	15.570	15.800
Sum	8.014	. 15.551	19.944	19.961	9,020	13.370	
Inte	r-element ratios						
XFe	0.7498				0.6197		
XMg	0.1986				0.0997		
XCa	0.0321				0.1915		
XMn	0.0195				0.0890		
Ån			22.0	33.5			
Ab			75.7	65.J			
0r			2.2	1.2			
Mg N	o. 20:9	50.5			13.9	40.0	37,9
1	84DMS-68, GT	2	84DHS-68, 810T	3	840MS-68, PLA	6	
47	84DMS-1118, PLAG 84DMS-1118, AMPH	5	840MS-1119, GT	6	840HS-1119, B	IOT	
				•			•

MEAN & STO DEVIATION FOR PHASES FROM HOST GNEISSES

				,		6	7
	1	2	3	*		RT	PLAG
	GT	BI	АМРН	PLAU	27 8 4- 0 4	75 4 44 7.0	62.0 +- 1.0
\$102	37.99 +- 0.31	34.98 +- 1.25	41.4 +- 0.4	23.2 +- 1.4	31.6 +- 0.4	1 8 4 7 8	-
1102	0.02 +- 0.03	4.44 +- 1.88	1.8 +- 0.1		-	4.3 - 2.4	21.8 += 1.0
A1203	21.01 +- 0.16	15.19 +- 2.14	12.1 +- 0.3	25.2 +~ 0.7	21.2 += 0.7	13.3 +- 3.4	
Cr203	0.01 +- 0.04	-	-		- +- U.2		-
Feû	30.09 +- 1.83	24.55 +- 1.96	21.8 +- 0.8	0.2 +- 0.4	28.7 +- 1.1	23.1 +- 3.3	-
MnO	1.96 +- 0.40	0.08 +- 0.04	0.1 + 0.3	-	5.3 +- 1.0	0.1 +- 0.3	_
Mg0	2.02 +- 0.43	7.24 +- 1.21	6.7 +- 0.3	•	2.4 +- 0.6	8.4 +- 1.1	5 7 an 0.1
CaO	8.18 +- 1.84	0.03 +- 0.05	11.7	7.3 +- 0.4	5.9 +- 0.9		g. 7 av 0.1
Na20	-	0.05 +- 0.06	1.3 +- 0.6	7.0 +- 0.3	-	0.1 +- 0.4	014007
K20	-	9.26 +- 0.51	1.7 +- 0.1	0.3 + 0.1	•	8.7 +- +.4	0,1 +- wiw
Total	101.28	95.82	98.6	99.2	101.3	95.1	33.4
Cation	\$				13 000	22.000	32.000
0	12.000	22.000	23.000	32.000	2,200	5.468	11.027
51	3.004	5.463	6.348	10.542	<b>č</b> , 333	0.519	1
71	0.001	0.521	0.202	-	1.979	2.822	5.001
A1	1,958	2.796	2.191	2.1++	0.002	•	-
Cr	0.001	-	-	-	1 900	2.584	-
F+2	1.990	3.206	2.794	0.030	n 157	0.010	-
Hn	0.131	0.011	0.010	-	0.288	1,927	-
Mg	0.238	1.685	1,531	-	0.100	-	1,014
Ca	0.693	0.005	1.921	1.412	0.450	0.021	2,830
Na	•	0.015	0.386	2,433	-	1.718	0.032
ĸ	-	1.845	0.328	0,060	8 017	15.471	19,904
Sum	8.016	15.548	15.712	19.943	8.0.0		
Inter-	element ration				0.6242		
XPe VM.	0.6519				0.0947		
Xrig Va					0,1637		
XLa	0.2271				0.1173		
X00	0,0430			36.0			28.2
				52.5			73.0
A0 A.				1.5			0.8
UP Ma No	10.7	74 K	35.4	<b>.</b>	13.2	39.2	
ng no.	10,7	34.3		_	A (DMP. 174 - 4M	PLÍ	
18	40MS-124, GT	2	840HS-124, GT	3	1 84003-144, AD	nt	
4 8	40MS-124, PLAG	5	840HS-173	6	84002-1(J, WL		
78	ADMS-173, PLAG		A-4	19			

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HEAN & STD DEVIATION FOR PHASES FROM GRANULITES

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	1	2	C	4	5	8	7
	AMPH	OPX	GT	· 81	PLAG	AMPH	ILM
\$102	40.0 +- 0.3	50.84 +- 0	0.20 38.16 +- 0.	19 35.98 +- 0.75	58.7 +- 0.6	39.9 +- 0.9	0.4 +- 0.1
T:02	2.1 +- 0.4	0.05 +- 0	0.03 -	5.53 +- 0.26	-	2.6 +- 0.3	45.3 +- 1.0
A1203	10.3 +- 0.5	i 1.54 +- (	0.20 21.14 +- 0.	23 13.68 +- 0.12	25.8 +- 0.3	12.5 +- 0.5	-
FeQ	27.7 +- 0.5	27.49 +- (	0.84 27.72 +- 0.	51 17.01 +- 0.60	-	17.8 +- 0.8	51.8 +- 0.7
MnO	0.2 +- 0.1	0.61 +- (	0.21 1.34 +- 1.	21 -	-	-	-
MgQ	3.8 +- 0.3	18.64 +- (	0.35 5.27 +- 0.	90 12.37 +- 0.67	-	8.5 +- 0.2	0.6 +- 0.1
CaO	10.8 +- 0.3	0.47 +- (	0.20	38 -	7.9 +- 0.2	11.3 +- 0.3	-
Na20	1.9 +- 0.3	-	-	-	6.7 +- 0.3	1.8 +- 0.5	-
K20	1.5 +- 0.2	-	•	9.60 +- 0.19	0.3 +- 0.1	2.1 +- 0.2	-
Total	98.4	99.64	100.34	94.17	99.4	96.4	98.1
Cation	ne -						
0	23.000	5.000	12.000	22.000	32.000	23.000	3.000
SL	6.356	1.952 ···	2.992	5.526	10.545	6.181	0.012
Ti	0.254	0.001	-	0.639	-	0.298	0.904
A1	1.932	0.070	1.954	2.476	5.459	2.279	-
F+2	3.674	0.883	1.818	2,185	-	2.301	1,147
No s	0.030	0.020	0.089	-	-	-	•
Mg	0.911	1.067	0.616	2.832	-	1.963	0.022
Ca	1.828	0.019	0.564	-	1.525	1.876	-
Na	0.579	-	•	•	2.322	0.547	-
ĸ	0.300	-	-	1.881	0.069	0.419	-
Sum	15.863	4.012	8.031	15.530	19.920	15.864	2.084
Inter-	element ratios						
XFe		0.4439	0.5889				
XMg		0.5364	0.1996				
XCa		0.0097	0.1827				
XMn	•	0.0100	0.0288				
An					39.0		
ÅЬ					59.3		
0r					1.0		
Mg Na.	19.9	54.7	25.3	56.5		46.0	1.9
1 8	50MSR-27, AMPH		2 850MSP-5A, 0P	ַ ד אי	850MSP-5A, GA	RNET	
4 8	50MSP-5A, 810T (	(WO)	5 850MSP-5A, PL	.AG 6	850MSP-5A, AN	PH	
7 8	SOMSP-5A, ILMENI	TE					

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MEAN & STO DEVIATION FOR PHASES FROM GRANULITES

		•	3	4 .	5	6
		rov	OPX	FSPR	PLAG	AMPH
		51.2 40 0.9	50.8 +- 1.2	64.0 +- 0.9	60.0 +- O.	.7 . 41.1 +- 1.3
5102	0.4 +- 0.1	37.2 7- 0.3	•	0.5 +- 0.2	-	1.9 +- 0.3
1102		254-05	1.4 +- 0.7	18.5 +- 0.2	25.0 +- 0.	,4 12.4 +- 0.7
A1203	-	11 0 += 0.0	28 9 +- 0.4	-	-	18.2 +- 0.9
Feu	86.9 4-10.0		0.8 += 0.2	-	-	-
Mn0	-		17.8 += 0.8	-	-	9.6 +- 0.8
MgO	-	12.0 +- 0.5	05 += 0.0	-	6.9 +- 0.	.3 11.8 +- 0.3
CaO	-	22.3 += 0.8	0.5 += 0.5	1.6 +- 0.5	7.3 +- 0.	.3 1.9 +- 0.3
Na20	-	1.0 ++ 0.2	-	14.7 += 0.9	-	1.8 +- 0.2
K20	•	-	-	99.3	99.2	96.7
Total	87.4	100.3	100.1	331.0		
<b>.</b>						
Latio	ons	e 000	6 000	32.000	32.000	23.000
0	4,000	6.000	1 950	11.881	10.745	6.220
51	0.024	1.312	1.330	0.066	-	0.214
TI	-	-	0.062	4.055	5.271	2.202
A1	•	0.112	0.052	-	-	2.306
FeZ	3,951	U.348	0.330	-	•	
Mn	-	0.012	0.023	_	-	2.164
Mg	-	0.673	1.022	-	1.329	1.904
Ca	-	0.900	0.019	0 569	2.550	0.563
Na	-	0.0/3	-	3 482	•	0.347
κ	-	•	-	20.051	19.895	15.920
Sum	3.976	4.049	4.013	20.031		
1	- alamant mation					
VP.	r-element ration	0 1798	0.4659			
AF U		0.3492	0.5120			
Ang VC-		0 4658	0.0095			
ALE VH_		0.0061	0.0126			
		0.0001			34.3	
10				14.0	65.7	
A0 0-				86.0		
UP 		CE 9	52.4			48.4
ng No	9,	63.3	4917			
		176 3	ASDMSP-16, CPX		3 850MSP-16,	OPX
2	030H3F-3A, HAUNEL	4 E	ASOMSP-16. PLAG		6 65DMSP-16.	RETROGRESSIVE AMPHIBOLE
•	030435+10; K+5354	3		-		

MEAN & STO DEVIATION FOR PHASES FROM HOST GNEISSES

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	1	2	3	4	5	6	7
	KFSP	ST	PLAG	KFSP	BIOT	CPX	GT
\$102	2 63.6 +- 2.9	39.6 +- Q.B	61.3 +- 1.2	64.2 +- 0.8	36.45 +- 0.57	51.49 +- 1.16	38.30 +- 0.81
T102	2 0.1 +- 0.3	-	-	0.1 +- 0.3	5.72 +- 0.45	0.22 +- 0.06	0.07 ++ 0.02
A120	20.4 +- 7.3	22.6 +- 0.5	24.2 +- 0.4	18.8 +- 0.4	14.18 +- 0.22	1.56 +- 0.47	21.41 +- 0.13
Fe0	•	26.6 +- 0.4	-	-	17.34 +- 0.56	11.12 +- 1.27	28.66 +- 1.82
MnO	•	0.1 +- 0.3	-	-	0.02 +- 0.04	0.07 +- 0.05	0.55 +- 0.04
MgO	•	10.9 +- 0.4	-	-	11.76 +- 0.34	11.78 +- 0.76	4.06 +- 0.10
CaO	-	1.3 +- 0.4	5.7 +- 0.4	-	0.01 +- 0.04	22.51 +- 0.66	8.03 +- 1.59
Na20	2.5 +- 5.0	-	8.0 +- 0.4	2.1 +- 1.1	0.04 +- 0.05	0.53 +- 0.13	-
K20	12.9 +- 7.3	-	0.3 +- 0.2	13.7 +- 1.7	9.91 +- 0.38	-	-
Tata	99.5	101.3	99.5	98.9	95.43	99.28	101.08
Cati	ions						
0	32.000	12,000	32.000	32.000	22.000	6.000	12.000
51	11.693	2,905	- 10.929	11.901	5.531	1,960	2.991
T1	0.014	-	-	0.017	0.653	0.006	0.004
A1	4.416	2.006	5.093	4.112	2.536	0,070	1.971
Fe2	-	1.677	•	-	2.200	0,354	1.872
No	4-	0,008	<b>-</b> .	•	0.003	0.002	0.036
Mg	-	1.229	-	-	2.660	0,668	0.473
Ca	-	0.107	1.097	- `	0.002	0,918	0.672
Na	0,892	-	2.765	0.762	0.012	0,03a	•
ĸ	3.034	-	0.071	3.231	1.918	-	-
Sum	20.048	8.012	19.944	20.022	15.514	4.018	8.019
Inte	r-element ratios					o 1033	0 6173
XFe		0.5550				0.1842	0.0/54
XMg		0.4068				0.377	0.1040
XCa		0.0355				0.9120	0.0119
XMn		0.0027				0.0012	0.0113
An			27.7				
Ab	22.7		70.5	19.1			
Or	77.3		1.8	80.9		or 1	t of
Mg N	۰.	42.3			24.1	•• 68	6U+6
1	840HS-173, K-FSPR	2	840MSA-150, GT	3	840MSA-160, PL	AG	
4	840MSA-160. K-FSPF	ı 5	850MSH-110A, 8	10T 6	850MSH-110A, C	PX	
7	850MSH-110A, GT						

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MEAN & STO DEVIATION FOR PHASES FROM METASEDIMENTS

		2	3	4	5	6	7
	91 A.G	АМРН	BIOT	GT	PLAG	<b>OPX</b>	67
6103	FLAU FD 0 to 1.2	41 6 AP 0.3	37.88 +- 0.91	39.24 +- 0.59	61.3 +- 0.8	49.99 +- 0.37	37.77 +- 0.37
1102	60.0 +- 1.3	2 4 4- 0 5	4.71 +- 1.02	0.02 +- 0.02	<b>-</b> '	0.08 +- 0.03	0.04 +- 0.01
1120		11 4 4- 0.5	17.12 +- 0.67	22.29 +- 0.20	24.3 +- 0.7	0.79 +- 0.17	21.02 +- 0.31
C-201	J 24.6 +- U.6	-	0.19 +- 0.11	0.06 +- 0.04	-	•	0.03 +- 0.06
C-0	, -	15 7 44 0 5	9.76 +- 2.14	29,15 +- 0.88	-	32.69 +- 0.91	29.58 +- 0.29
r 40	•	10.0 +- 0.0	0.02	0.31 +- 0.02	-	0.53 +- 0.14	1.56 +- 0.10
rinu N. O	•		16 02 4- 1.50	8.91 +- 0.73	-	14.67 +- 0.68	3.08 +- 0.33
ngu	-	41 0 - 0 8	18105 * 110-	1.44 +- 0.25	6.0 +- 0.3	0.81 +- 1.06	7.29 +- 0.17
Lau	7.3 += 1.0	1.5 += 0.3	0 10 4- 0 08	•	7.8 +- 0.4	-	-
Nazu	r,u += u.3	1.0 +- 0.1	0.10 += 0.00	-	0.3 +- 0.3	-	-
KZU	0.5 += 0.3	1.7 +* 0.2	9.33 4- 0.33	101.42	99.6	99.56	100.37
Tota	1 99.3	96.3	33.34	101.44			
Catio	ene					e 000	12.000
0	32.000	23.000	22.000	12.000	32,000	4 973	2.996
Si	10.759	6.340	5.501	2.991	10.912	1.3/3	0.002
71	-	0.279	0.514	0.001	-	0.002	1.966
Al	5.238	2.054	2.930	2.002	5.106	0.037	0.002
Cr	-	-	0.022	0.004	•		1 967
Fe2	-	2.079	1.137	1.858	•	1.0/9	0.105
Mn	-	-	-	0.020	-	0.010	0 764
Ng	-	2.257	3.470	1.012		U.86J	0 620
C.	1.357	1.936	-	0.118	1.139	0.034	0.040
Na	2,420	0.488	0.028	-	2.587	-	-
ĸ	0.114	0.331	1.840	-	0.068	4 000	
Sum	19,889	15.763	15.442	8.005	19.913	4.008	
tata							
YEA	L-010WBUE L90104			0.6177		0.5411	0.6432
YMa				0.3365		0,4328	0.1194
VP.				0.0391		0.0172	0,2031
YMe				0.0067		0,0089	0.0344
Arm Am	<b>14</b> 0				29.3		
11	J7.3			,	69.0		
60 0	54.4				1.0		
ur Na N	<b>č.3</b>	82 1	75.3	35.3		44.4	15.7
-0 <b>9</b> -14		36,1	13.0				
1	850MSH-110A, PLAG	2	BSDMSH-110. AM	рн Э	850HSG-111A,	BIUT	
4	850MSH-111A. GT	5	850HSH-111A, P	LAG &	850MS0-76, OF	'K	
7	850MSD-76, GT	-					

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MEAN & STD DEVIATION FOR PHASES FROM HETASEDIMENTS

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	1	2	з	4	5	6	7
	BIOT	PLAG	BI	GT	OPX	PLAG	ILM
\$102	35.60 +- 0.30	58.4 +- 0.9	36.42 +- 0.33	27.97 +- 0.44	50.83 +- 0.68	58.3 +- 1.0	0.4
T102	5.40 +- 0.26	-	4.84 +- 0.59	0.03 +- 0.04	0.10 +- 0.04	-	52.3 +- 0.3
A1203	14.65 +- 0.35	25.9 +- 0.5	14.20 +- 0.29	20.99 +- 0.31	0.78 +- 0.18	26.0 +- 0.5	-
C+203	0.04 +- 0.05	-	-	-	-	-	
F+O	20.54 +- 0.63	0.2 +- 0.8	18.37 +- 0.46	29.03 +- 0.66	31.33 +- 0.75	-	46.7 +- 0.6
MnQ	- +- 0.02	-	0.04 +- 0.04	1.63 +- 0.20	0.61 +- 0.09	-	0.6 +- 0.1
MaQ	10.03 +- 0.48	0.1 +- 0.4	11.49 +- 0.44	3.69 +- 0.66	15.65 +- 0.69	-	0.4
Ca0	-	8.4 +- 0.5	-	6.79 +- 1.14	0.67 +- 0.21	8.3 +- 0.4	-
Na20	0.03 +- 0.05	6.6 +- 0.6	0.04 +- 0.04	-	-	£.6 +- 0.3	-
K20.	9.63 +- 0.14	0.3 +- 0.2	9.65 +- 0.15	-	-	0.2 + 0.2	-
Total	95.92	99.0	95.05	100.13	99.97	99.3	100.5
Cation							2 000
0	22,000	32.000	22.000	12.000	6.000	10 487	0.010
Si	5,455	10.474	5.566	3.007	1.981	10.487	0.000
Ti	0.622	-	0.556	0.002	E00.0		4.304
AL	2.646	5.475	2.558	1.959	0.036	3.312	-
Cr 4	4 0,005	-	<b>-</b> .	-	-	-	0 079
Fe2	2,632	0.033	2.348	1.923	1.021	-	0.313
Mn	-	-	0.005	0,109	0.020	-	0.015
Ng	2.291	0.024	2.618	0.436	0.909	-	0.014
Ca	-	1.607	-	0.576	0.028	1.234	-
Na	0,009	2.281	0.012	-	-	6.204	-
ĸ	1.883	0.069	1,882	-	-	0,040	2 004
Sum	15.543	19,963	15.545	8.012	J.998	19.924	2.004
Totora	alement ratios						
YFe				0.6317	0.5161		
XHa	•			0.1431	0.4595		
YCa	•			0.1893	0.0141		
YMo				0.0359	0.0102		
Å.		40.6				40.6	
46		57.7				58.2	
<u>0</u> .		1.7				1.2	
Ma No.	46.5	42.2	52.7	18.5	47.1		1.5
1 9	SDMSD-76, BIOT	2	850HS0-76, PLAG	; 3	850MS0-138Å, 1	BIDT .	
4 B	SDMSD-138A, GT	5	850MS0-138A, 0P	× 6	850MS0-138A, 1	PLAG	
7 8	SDMSD-138A, ILMEN	ITE					

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MEAN & STD DEVIATION FOR PHASES FROM METASEDIMENTS

	•		3	4	5	6	7
	eT.	BIOT	PLAG	810T	61	PLAG	CPX
\$102	AD. 77 ++ 0.81	38.45 +- 0.88	62.0 +- 1.1	35.50 +- 0.34	37.60 +- 0.53	60.8 +- 1.2	51.4 +- 0.5
T+02	0.01	4.51 +- 0.86	-	2.80 +- 0.42	0.05 +- 0.09	-	-
1104	22 15 An II 74	15.78 +- 1.21	23.8 +- 0.6	19.67 +- 0.29	21.59 +- 0.50	24.1 +- 0.5	0.3 += 0.5
C-203	-	0.01 += 0.03	-	0.02 +- 0.08	0.01 +- 0.05	-	•
Eall	20 28 4- 2 24	5.83 +- 2.14	-	17.32 +- 0.33	34.62 +- 1.73	-	16.2 +- 0.9
F#0	0.55 += 0.08	-	-	-	0.71 +- 0.16	•	D.4 +- D.1
MeD	15 04 4- 1 73	19 51 += 1.70	•	10.21 +- 0.42	4.05 +- 0.83	-	7.9 +- 0.4
ngu C-0	13.04 += 1.13		5.3 +- 0.5	-	2.43 +- 0.98	6.0 +- 0.4	24.3 +- 0.5
N-30	0.83 ** 0.05	0.26 ++ 0.28	8.1 +- 0.5	0.23 +- 0.04	-	7.9 +- 0.4	0.2 +- 0.5
7860	•	9 84 4- 1 01	0.3 +- 0.1	9.24 +- 0.18	-	0.1 +- 0.1	•
Total	-	95.19	99.3	94.99	101.06	99.0	100.8
Cation	•			22 000	12.000	32.000	6,000
a	12,000	22.000	32,000	22.004	2.975	10.907	1.988
Si	2.995	5.498	11.054	3.333	0 003		•
Ti	-	0,485	-	3 499	2.014	5.094	0.014
A1	2.004	2.828	4.968	3.434	0.001		-
Cr	-	0.001	-	3 105	2 291	-	0.523
F+2	1.252	0.697	-	4.103	0.048	•	0.014
Hn	D.034	-	•	3 300	0.478	•	0.454
Mg	1,647	4.159	-	£,230	0.206	1.160	1.005
Ca	0.070	•	1.020			2.740	0.011
Na	-	0.072	2.782	0.06/	_	0.030	-
ĸ	-	1.795	0.061	1,116	8 015	19.931	4.011
Sum	8,003	15.536	19,884	13.500			
Inter-	lement ratios						0.2619
XFe	0.4169				0.7580		0.2274
XMg	0.5484				0.1501		0.5038
XCa	0.0233				0.0684		0.0071
XHn	0.0114				0.015/	29.5	
An			26.4			69.7	
Ab			72.0			0.8	
0e			1.6			•••	46.5
Mg No.	56.8	85.6		51.2	11.3		-
1 85	SDMSP-7, GT	. 2	050MSP-7, 010T	t	850HSP-7, PLAC	1	
4 85	TOMSP-13A, BLOT	S	650MSP-13A, GT	6	#50HSP-134, PL	.AU	
7 84	DMS-918, CPX		A-	-52			

	1	2	Э	4	5	6	7
	PLAG	KFSP	GT	CPX	VES	PLAG	WOLL
5102	2 61.7 +- 0.9	63.9 +~ 1.0	39.2 +-	0.3 52.4 +- 1.	3 36.5 +- 0.	7 61.0 ++ 0.1	51.0 +- 0.5
1102	-	- +- 0.2	0.2 +-	0.3 -	2.6 +- 0.	2 -	-
A120	3 23.9 +- 0.7	18.4 +- 0.4	20.2 +-	0.7 0.8 +- 0.3	2 16.5 +- 0.	6 24.4 +- 0.8	0.1 +- 0.3
Cr20	- CI	-	-	•	-	-	-
F+0	•	-	4.8 +-	0.7 10.0 +- 1.1	6 2.6 +- 0.	3 -	-
MnØ	-	•	0.5 +-	0.2 0.1 +- 0.3	3 - +- 0.	2 -	-
MgQ	-	-	-	11.6 +- 0.5	1.8 +- 0.	3 -	-
CaO	5.5 +- 0.5	- +- 0.2	35.5 +-	0.8 24.6 +- 0.5	36.2 +- 0.	7 5.8 +- 0.4	48.7 +- 0.8
Na20	8.0 +- 0.8	0.8 +- 0.3	-	0.3 +- 0.5	5 -	7.7	-
K20	0.2 +- 0.2	15.9 +- 0.5	-	-	-	0.2 +- 0.1	-
Tota	1 99.3	99.0	100.4	99.8	96.3	99.0	99.8
Cati	ons						
0	32.000	32.000	12.000	5.000	36.000	32.000	3.000
Si	11.000	11.942	2.997	1.982	8.776	10,904	0.992
Ti	-	0.006	0.012	-	0.477	-	-
A1	5.024	4.042	1.824	0.035	4.660	5.145	-
Cr	· -	-	-	-	-	-	0.001
F+2	-	-	0.308	0.317 .	0.530	•	-
Hn	•	-	0.030	0.004	0,008	-	•
Ng	-	-	-	0.656	0,652	•	-
Ca	1.055	0.006	2,909	0.997	9.316	1.121	1.015
Na	2.780	0.279	-	0.019	-	2.671	- '
ĸ	0.036	3.792		-	-	0.034	- '
Sum	19.896	20.066	8.090	4.010	24.418	19.876	2.008
Inter	-element ratios						
XFe			0.0950	0.1606			
XHg				0.3325			
XCa			0.8957	0.5050			
XMa.			0.0094	0.0019			
An 👘	27.2	0,1				29.3	
Ab	71.8	6.8				69.8	
] e	0.9	93.0				0.9	
ig No	•			67.4	55.1		
1	840MS-918, PLAG	2	84DMS-918,	K-FSPA :	840HS-918, G	T	
4	84DMS-99A, CPX	5	840MS-99A,	VESUVIANITE	84DHS-99A, P	LAG	
7	840HS-172A, WOLL						

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MEAN & STO DEVIATION FOR PHASES FROM MARBLES AND CALC-SILICATES

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MEAN & STO DEVIATION FOR PHASES FROM MARBLES AND CALC-SILICATES

	1	ı	2	Э	• 4	5	6	7
	SC	CAP	PLAG	CPX	GT	CPX	PLAG	SCAP
SiO	2 41.9 4	a.0	61.2 +- 1.1	53.2 +- 1.1	37.8 +- 1.5	46.5 +- 1.	.1 48.8 +- 2.5	46.0 +- 1.0
TiO	2 -		<b>-</b> ·	-	- +- 0.2	0.2 +- 0.	.3 – 6.	-
A12	03 23.3 4	- 0.4	23.7 +- 0.3	0.9 +- 0.8	15.2 +- 2.5	3.1 +- 0.	.8 31.5 +- 1.8	26.6 +- 0.1
Fe0	0.2 +	- 0.4	-	6.7 +- 0.6	18.8 +- 1.8	23.9 +- 1.	4 - +- 0.2	•
Mn0	-		-	- +- 0,2	0.6 +- 0.4	-	-	-
MgQ	-		-	13.7 +- 0.4	0.1 +- 0.4	<b>3.0 +- 0</b> .	8 -	•
Call	26.8 +	- 0.6	5.5 +- 0.3	25.0 +- 0.2	28.4 +- 2.4	22.2 +- 0.	5 15.4 +- 1.9	17.5 +- 0.1
Na2	- C		7.9 +- 0.3	0.3 +- 0.6	0.1 +- 0.6	0.6 +- 0.	5 2.8 +- 1.0	3.3 +- 0.1
K20	-		0.2 + 0.1	-	-	•	0.1 +- 0.2	0.6 +- 0.1
Tota	92.1		98.5	99.8	99.0	99.6	98.6	94.1
Cati	ions							
0	24.000		32.000	6.000	12.000	5.000	32.000	32.000
Si	6.541		11.011	1.982	3.082	1.893	9.051	9.123
71	-		-	-	0.002	0.005	-	-
A1	4.278		5.016	0.030	1.457	0.147	6.885	6.223
Fe2	0.020		-	0.208	1.282	0.812	0.006	-
Mn	-		-	0.001	0.044	-	•	-
Mg	-		•	0.761	0.009	0.179	•	•
Ca	4,483		1.056	0.998	2.306	0.967	3.061	3.725
Na	-		2.741	0.022	0.011	0.051	0.993	1.248
ĸ	-		0.055	•	-	•	0.014	0.139
Sum	15,321		19.879	4.010	8.192	4.054	20.010	20.459
Inte	r-element rat	tios						
XFe				0.1056	0.3521	0.4147		
XMg				0.3865	0.0023	0.0912		
XCa				0.5072	0.6334	0.4940		
XMn				0.0006	0.0121			
Ап			27.4				75.2	
Ab			71.2				24.4	
0e			1.4				0.3	
Mg N	•.			78.5	0.7	18.0		
1	840MS-172A,	SCAPOLI	1E 2	840H5-172A, PL	,AG 3	840HS-172A.	CPX	
4	840MSA-178,	GT	5	840MSA-179, CP	<b>s</b> x	840HSA-178.	PLAG	
7	840HSA-178,	SCAPOLI	IE ,					

	1	2		3	4	5	6	,
• • •	KFS	iP CP:	K	WOLL	SCAP	GT	AMPH	Rt
51	32 64.8 +-	1.2 53.7 +	- 0.7 51.0	5 +- 0.4 44.9	3 +- 0.3 3	8.8 +- 0.9	42.8 +- 1.3	36.5 += 0.6
TIC	32 -	-	-	-	•	-	1.0 +- 0.6	3.4 += 1.1
AL	203 18.6 +-	0.3 1.3 +-	- 0.2 -	27.5	5 +- 0.4 2	2.0 +- 0.7	14.6 +- 1.1	16.1 += 1.6
Fel	· -	5.8 +-	- 0.6 -	-	2	5.1 +- 3.4	13.7 +- 0.8	14.3 +- 0.8
Hot	- (	-	-	-		0.9 +- 0.2	•	•
MgC	I –	14.1 +-	· 0.5 -	-		6.4 +- 1.1	11.7 +- 1.2	14.0 += 0.3
Cal	-	25.4 +-	0.5 48.3	+- 0.4 19.0	+- 0.4	6.7 +- 4.5	11.1 += 0.8	0.5 - 1.4
Na2	0 1.1 +-	0.4 -	0.1	+~ 0.4 3.0	+- 0.4	-	1.9 +- 0.4	-
K20	15.4 +-	0.4 -	-	0.2	+- 0.2	-	0.5 +- 0.1	8.7 - 0.8
Tot	al 99.9	100.3	100.0	94.6	10	1.1	97.4	97.6
Cat	ions							
0	32.000	6.000	3.000	24.000	12.0	. 00	23.000	22.000
SL	11.959	1.980	0.998	6.664	2.9	86	6.310	5.516
TI	-	-	-	-		•	0.115	0.386
A1	4.052	0.054	-	4.810	1.9	198	2.537	2.877
Fe2	-	0.180	-	-	1.6	77	1.692	1.807
Нn	4 -	-	-,	-	0.0	61	•	
Mg	-	0.775	-	-	0.7	38	2.580	3 154
Ca	-	1,003	1.002	3.012	0.5	55	1.752	0 081
Na	0.387	-	0.004	0.857	-		0.546	-
ĸ	3.622	-	_	0.034	-		0.094	1.677
Sum	20.020	3.992	2.004	15.377	8.0	15	15.626	15.498
Inte	r-element ratio	0 8						
XFe		0.0917			0.55	34		
XMg		0.3960			0.24	36		
XCa		0.5123			0.18	30		
XMn					0.020	00		
ÅЬ	9.6							
0r	90.4							
Mg No	<b>.</b>	81.2			30.	8	60.4	6J.5
1	840HSA-161C, #	-FSPA	2 84DMSA-1	ISIC, CPX	3 8401	ISA-161C. WOL	L	•
4	BADMSA-161C, S	CAPOLITE	5 840MS-27	C, GT	6 640H	S-27C, AMPH	-	
7	840MS-27C, 810	T						

MEAN & STD DEVIATION FOR PHASES FROM MARBLES AND CALC-SILICATES

MEAN & STO DEVIATION FOR PHASES FROM ANORTHOSITES, LEUCOGABOROS & AMPHIBOLITES

	1	2	3	4	5	6	7
	PLAG	AMPH	PLAG	Анрн	GT	PLAG	Bt
\$10	2 51.1 +- 3.8	42.8 +- 3.0	53.2 +- 3.1	42.8 +- 1.3	38.8 +- 0.6	49.6 +- 1.2	36.7 +- 1.1
TIO	2 -	0.4 +- 0.5	• •	0.8 +- 0.3	-	-	2.3 +- 0.3
A12	03 31.0 +- 2,5	15.3 +- 4.9	29.0 +- 1.6	14.8 +- 1.1	21.8 +- 0.6	31.8 += 1.1	16.5 +- 0.4
FeQ	0.1 +- 0.4	11.9 +- 2.9	- +- 0.2	13.9 +- 0.5	27.3 +- 1.3	-	13.7 +- 1.4
MnQ	-	0.1 +- 0.3	-	- +- 0.2	1.6 +- 0.4	-	-
MgQ	-	12.2 +- 3.8	-	12.0 +- 1.0	7.5 +- 1.0	•	16.5 +- 0.4
CaO	13.7 +- 2.7	11.3 +- 0.4	11.9 +- 2.0	11.0 +- 0.3	4.1 +- 0.6	15.1 +- 1.1	0.2 +- 0.6
Na2	0 3.7 +- 1.6	2.6 +- 0. <del>9</del>	4.8 +- 1.2	1.9 +- 0.2	-	3.0 +- 0.8	-
K20	-	0.4 +- 0.2	-	0.5 +- 0.2	•	•	7.9 +- 0.8
Tati	al 99.6	97.0	98.9	97.5	101.2	99.6	94.2
Cat	lans						
0	32.000	23.000	32.000	23.000	12.000	32.000	22.000
Sı	9.326	6.293	9.725	6.283	2.986	9.085	5.457
Ti	-	0.041	-	0.090	-	-	0.257
A1	6.661	2.659	6.250	2.566	1.978	6.878	2.901
F+2	0.014	1.467	0.005	1.713	1.758	•	1.704
Mn	-	0.009	-	0.004	0.108	•	
Mg	•	2.576	-	2.629	0.859	•	3.735
Ca	2.687	1.783	2.329	1.745	0.337	2.972	0.032
Na	1.310	0.739	1.684	0.543	-	1.081	-
ĸ	•	0.077	-	0.068	•	•	1.499
Sum	19.998	15.745	19.992	15.661	8,025	20.016	15.585
Inte	r-element ratios						
XFe					0.5742		
XMg					0.2806		
XCa					0.1101		
XMn					0.0351		
Ån	67.2		58.0			73.3	
Ab	32.6		42.0			26.7	
Mg N	o.	64.6		60.5	32.8		68.7
1	840HS-27C, PLAG	2	840MS-35C, AMPH	3	840HS-35C. PL/	G	
4	840MS-570, AMPH	5	840MS-570, GT	6	840MS-570, PLA	0	

7 840HS-570, 810T

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	1	2	3	4	5	e	•
	AMPH	AMPH	HICA	GT	PLAG	ÁMPU	r 7 M
5102	43.7 +- 1.4	54.4 +- 2.1	29.2 +-	1.2 38.4 +- 0.1	8 51.8 +- 1	.R 413 4-33	
T102	0.3 +- 0.4	-	-	-		07.4-08	U.3 \$1.2
A1203	14.4 +- 2.2	0.6 +- 0.3	16.9 +- (	0.8 21.3 +- 1.3	3 30.0 +- 1.	4 16 L an 1 L	31.3 += 3.0
Cr203	-	•	-	-	•		
FeQ	12.4 +- 0.6	13.6 +- 2.7	21.5 +- 1	1.7 28.0 +- 1.	ı -	16 6 4- 8 8	17 7
MnQ	- +- 0.2	0.1 +- 0.3	-	1.4 +- 0.2	-	0 1 4= 0 2	
MgQ	12.1 +- 0.8	15.4 +- 2.3	19.3 +- 0	).2 7.3 +- 0.1	- +- 0.	2 894-34	
CaQ	10.6 +- 0.4	12.9 +- 0.3	0.4 +- 0	.4 3.7 += 0.9	17 1 4 1	5 11 7 0 7	0.3 +- 0.8
Na 20	2.2 +- 0.4	-	0.1 +- 0	1.4 -	4.7 en R		
K20	0.3 +- 0.1	-	-	-		0 2.1 - 0.4	1.3 +- 3.5
Total	97.0	97.2	87.4	99.9	99.1	97.3	101.8
F-++-							
	33 000						
с. С.	23.000	23.000	22.000	12.000	32.000	53.000	3.000
71	0.001	7.764	4.737	2.996	9.493	6.068	0.012
11	0.031		-	-	-	0.094	0.961
<u> </u>	15.423	0.328	3.234	1.950	6.468	2.909	-
5.3		-	•	-	-	0.030	0.004
N-	1.323	2.026	2.916	1.825 -	-	2.093	D.994
Ma	0.005	0.015	-	0.091	•	0.008	0.012
	4.852	3.878	4.680	0.846	0.006	1.999	0.011
4.8 N-	1.657	1.024	0.063	0.310	2.563	1.824	-
na v	4.614	0.073	0.031	-	1.484	0.607	0.060
R.	0.054	•	-	-	-	0.121	-
3UM	15.645	15.108	15,662	8.025	20.016	15.743	2.055
Inter-	element ratios						
XFe				0.5942			
XMg				0.2755			
XCa				0.1008			
XMm				0.0295			
An					63.3		
ÅЪ					36.7		
Mg No.	65.2	65,7	61.6	31.7		48.8	1.1
1 84	OMS-134A, HBI	, 2	840MS-1344		01040-4014		
4 84	DHS-134A, GT		RADMS-1344. F		840H2-134A, (	ACUAILE	
7 84	DHS-134C. ILMENIT	E		CAG 0	04013413461 1	19 <b>17 11</b>	

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MEAN & STO DEVIATION FOR PHASES FROM ANORTHOSITES, LEUCOGABBROS & AMPHIBOLITES

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MEAN & STO DEVIATION FOR PHASES FROM ANORTHOSITES, LEUCOGABBROS & AMPHIBOLITES

	1	2	3	4	5	6	7
	PLAG	GT	CPX	AMPH	PLAG	EP10	CPX
SID	2 53.0 +- 2.5	38.1 +- 0.5	49.3 +- 0.B	39.3 +- 0.6	58.0 +~ 0.8	37.9 +- 0.6	50.96 +- 1.17
T102	2 -	-	0.4 +- 0.2	1.3 +- D.B	-	-	0.33 +- 0.21
A120	03 30.0 +- 2.1	21.5 +- 0.4	2.7 +- 0.4	12.7 +- 0.4	26.1 +- 1.1	23.8 +- 0.9	3.30 +- 1.38
Cr20		0.1 +- 0.2	-	-	-	-	0.04 +- 0.06
Fe0	0.1 +- 0.5	31.0 +- 2.3	14.2 +- 1.0	23.3 +- 2.4	-	11.3 +- 1.0	10.14 +- 1.07
MnO	-	1.8 +- 1.0	0.3 +- 0.3	0.2 +- 0.5	-	0.1 +- 0.3	0.18 +- 0.03
MgO	-	3.8 +- 0.8	8.9 +- 0.3	6.2 +- 1.2	-	-	12.34 += 0.63
CaO	12.6 +- 2.2	5.4 +- 0.5	22.8 +- 0.6	11.8 +- 0.2	8.3 +~ 0.5	23.3 +- 1.7	21.90 +- 1,26
Na20	6.4 += 1.1	-	0.7 +- 0.8	1.3 +- 0.3	6.5 +- O.E	0.1 +- 0.5	0.57 +- 0.15
X20	-	-	-	2.0 +- 0.2	0.2 +~ 0.2	0.2 +- 0.7	0.03 +- 0.05
Tata	1 100.1	101.7	99.3	98.2	99.1	96.7	99.79
Cati	ona						
0	32.000	12.000	6.000	23.000	32.000	13.000	6.000
Si	9.587	2.982	1.913	6.139	10.461	3,230	1.919
Ti	-	-	0.011	0.155	-	•	0,009
A1	6.393	1,987	0.125	2.343	5,544	2.386	0,146
Cr	•	0.003	•	<b>-</b> '	-	-	0.001
Fe2	0.019	2.031	0.462	3.045	-	0.805	0.319
Mn	-	0,119	0.009	0.032	-	0.007	0.008
Mg	-	0.443	0.518	1.454		-	0.693
Ca	2.444	0.457	0,948	1.973	1.595	2.126	0.001
Na	1.547	-	0.055	0.382	2.282	0.021	0.042
ĸ	•	-	-	0.407	0.053	0.022	0.001
Sum	19.989	8.023	4.041	15.929	19.935	8.598	4.020
Inter	r-element ratios						
XFe Vu.		0.6659	0.2384				0,15/9
Ang Ve		0.1451	0.2675				U.J64J
XLB		0.1500	0,4893				0,4647
A00		0.0389	0.0048				0.0010
AR 46	61.2				40.6		
AQ 0-	79.6				58.1		
ur Mg Na		17.9	52.9	32.3	1.3		68.4
4				· _	ALCHE 183 587		
	ALONE 100 AUG	2	840MS-134C, GT	3	010HC-102 - CPA	n076	
7	840MS-518, CPX	5	84UM5-182, PLAG	G	840034184, EFU		
			A-55				

MEAN'& STD DEVIATION FOR PHASES FROM ANORTHOSITES, LEUCOGABBROS & AMPHIBOLITES

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	1	2	3	4	5	6	7
	GT	6T	Анрн	PLAG	OP	CPX	GT
SIO	2 38.63 +- 0.36	39.09 +- 0.32	43.37 +- 3	.24 50.5 +- 5.2	0.9 +- 1.1	52.77 +- 0.77	39.27 +- 0.27
Tiū	2 0.05 +- 0.06	0.07 +- 0.04	1.20 +- 0.	.75	45.4 +- 3.8	0.24 +- 0.12	0.09 +- 0.03
A12	21.06 +- 0,17	21.10 +- 0.22	11.48 +- 2.	.61 30.8 +- 3.0	0.1 +- 0.3	2.05 +- 1.00	21.69 +- 0.47
Cr2	03 0.01 +- 0.04	0.02 +- 0.06	-	-	-	-	•
Fe0	26.66 +- 1.45	24.47 +- 1.31	15.45 +- 1.	.25 0.2 +- 0.7	48.7 +- 9.2	8.46 +- 0.82	25.46 +- 0.87
MnÖ	1.33 +- 0.25	0.61 +- 0.33	-	-	0.2 +- 0.3	0.09 +- 0.02	0.57 +- 0.18
NgQ	5.13 +- 0.54	6.45 +- 0.60	11.29 +- 1.	.64 0.1 +- 0.4	0.6 +- 0.6	13.10 +- 0.74	6.28 +- 0.27
CaO	7.98 +- 1.96	9.07 +- 1.12	11.81 +- 0.	18 14.2 +- 3.7	0.2 +- 0.4	22.76 +- 0.97	7.85 +- 0.77
Na2	0 -	-	1.54 ↔ 0.	44 3.4 +- 2.2	-	0.65 +- 0.35	-
K20	-	-	0.71 +- 0.	37 0.1 +- 0.7	-	-	-
Tat	al 100.85	100.88	96.85	99.2	96.0	100.13	101.21
Cati	ions						
0	12.000	12.000	23.000	32.000	3.000	6.000	12.000
\$1	3.006	3.008	6.511	9.266	0.033	1.964	3.010
TL .	0.003	0.004	0.135	•	0.933	0.007	0.005
A1	1.932	1.914	2.032	6.670	0.003	0.090	1.959
Cr	40.001	0.001	-	-	-	-	-
F#2	1.735	1.575	1.940	0.034	1.031	0.263	1.632
Mn	0.088	0.040	-	-	0.003	0.003	0.037
Mg	0.595	0.740	2.527	0.014	0.025	0.727	0.717
Ca	0.665	0.748	1.900	2.797	0.005	0.907	0.645
Na	•	-	0.448	1.218	<b>-</b> '	0.047	-
ĸ	-	-	0.136 "	0.019	-	•	-
Sum	8.025	8.030	15.629	20.017	2,033	4.009	8,005
Inte	r-element ratios						
XFe	0.5627	0.5076			•	0.1385	0.5384
XNg	0.1930	0.2385				0.3024	0.2367
XCa	0.2158	0.2411				0.4776	0.2127
XMnj	0.0284	0.0128				0.0015	0.0122
An				69.3			
АЪ				30.2	•		
Dr				0.5			
Mg No	. 25.3	32.0	56.6	28.8	2.4	73.4	30.5
1	840MS-518, GT RIN	2	84DMS-518,	GT CORE	3 840MS-518, A	1PH	
4	840HS-519, PLAG	5	840MS-518,	ILMENITE	6 850MSR-6, CP	K	
7	05DMSR-6, GT RIM						

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MEAN & STO DEVIATION FOR PHASES FROM ANORTHOSITES, LEUCOGABBROS & AMPHIBOLITES

DEAN &	STU DEVIATION FO	0H PHASES FHUR A	3	4	5	6	7
	, • 13	PLAG	AMPH	CPX	AMPH	PLAG	GT
5102	38.97 +- 0.75	59.5 +- 1.8	41.4 +- 0.1	51.6 +- 0.9	42.8 +- 4.9	49.9 +- 4.9	37.7 +- 0.6
T102	0.10 +- 0.02	-	2.5 +- 0.3	0.3 +- 0.3	1.0 +- 0.3	-	-
A1203	21.66 +- 0.44	25.3 +- 1.2	12.4 +- 0.8	1.7 +- 0.8	12.5 +- 5.4	30.9 +- 2.5	21.3 +- 0.8
Cr203	0.01 +- 0.04	•	0.1 +- 0.1	•	0.1 +- 0.4	-	-
FeQ	25.35 +- 1.75	-	15.1 +- 0.4	9.8 +- 1.0	16.9 +- 2.4	•	28.5 +- 1.5
MnQ	0.87 +- 1.02	-	0.2 + 0.2	-	-	-	0.4 +- 0.2
MaO	5.55 +- 2.71	-	10.8 +- 0.4	12.0 +- 0.3	9.3 +- 2.7	•	3.4 +- 0.3
CaO	8.75 +- 1.21	7.3 +- 1.4	11.6 +- 0.3	24.4 +- 0.4	12.2 +- 0.2	14.8 +- 3.4	10.2 +- 1.2
Na20	-	7.2 +- 0.8	2.4 +- 0.1	•	1.2 +- 0.3	3.4 +- 1.8	•
K20	•	0.1 +- 0.2	0.6 +- 0.1	•	0.9 +- 0.5	- +- 0.2	•
Total	101.26	99.4	97.0	99.9	96.9	99.0	101.4
Cation	•						
0	12.000	32,000	23.000	6.000	23.000	32.000	12,000
Si	2.998	10.656	6.241	1.948	5.468	9.201	2.956
TL	0.006	0.001	0.200	0.009	0.111	-	•
A1	1.964	5.341	2.200	0.077	2.231	6.714	1,963
Cr	0.001	-	0.016	-	0.012	•	-
F+2	1.631	-	1.909	0.308	2,134	•	1.854
Mn	0.057	•	0.019	-	-	-	0.025
Нg	0.636	-	2.422	0.677	2.092	-	0.357
Ca	0.721	1.411	1.875	0.985	1,982	2.922	6.823
Na	-	2.498	0.711	-	0.364	1.201	•
ĸ	-	0.027	0.110	-	0.170	0.007	-
Sum	8.014	19,935	15.782	4.004	15.565	20.046	
Inter-e	lement ratios						
XFe	0.5356			0.1565			0.3357
XMg	0.2090			0.3434			0.1203
XCa	0.2368			0.5001			0.0000
XMn	0.0186					70 7	0,0000
An		35.0				29.1	
Ab _		63.5				0.2	
0r		0.7					17.5
Mg Ne.	28.1		55.9	68.7	43.3		
1 85	DMSR-6, GT CORE	1	85DHSR-6, PLA	10	3 850HSR-8, AP	1PH	
4 85	IDMSR-16A, PRIM C	PX S	850MSR-16A, J	лнрн	6 850MSR-16A.	TLAU	
7 85	OMSR-16A, GT		A-56				

MEAN & STO DEVIATION FOR PHASES FROM ANORTHOSITES, LEUCOGABBROS & AMPHIBOLITES

	1	2	3	4	5	6	7
	CPX	GT	PLAG	АМРН	81	CPX	AMPH
S10	2 51.22 +- 1.14	39.03 +- 0.18	55.4 +- 1.0	39.8 +- 0.5	37.1 +- 1.4	52.1 +- 1.6	43.2 +- 1.2
Ti0	2 0.39 +- 0.12	-	-	1.7 +- 0.4	4.4 +- 1.0	- +- 0.2	1.4 +- 0.5
A12	03 4.11 +- 0.80	21.35 +- 0.26	27.9 +- 0.8	13.9 +- 0.4	14.1 +- 0.8	1.9 +- 0.4	10.5 +- 0.8
Cr2	03 -	-	-	0.1 +- 0.2	-	-	-
F+0	9.68 +- 2.06	26.72 +- 0.83	- +- 0.3	18.0 +- 1.7	17.2 +- 1.2	10.1 +- 0.8	15.3 +- 1.2
MnO	0.07 +- 0.03	0.70 +- 0.04	-	-	0.1 +~ 0.3	0.6 +- 0.3	0.3 +- 0.3
Mgū	11.61 +- 1.03	6.31 +- 0.61	-	8.4 +- 1.1	13.1 +- 1.3	12.1 +- 0.3	11.2 +- 0.9
CaO	22.65 +- 0.47	7.14 +- 1.14	10.5 +- 0.6	11.8 +- 0.2	- +- 0.2	21.5 +- 0.7	11.6 +- 0.6
Na2I	0.88 +- 0.02	-	5.5 +- 0.5	1.4 +- 0.3	0.3 +- 0.6	0.9 +- 0.2	1.7 +- 0.6
K20	-	-	0.3 + 0.1	2.3 +- 0.2	9.7 +- 0.4	-	1.4 +- 0.2
Tota	1 100.61	101.25	99.5	97.4	96.1	99.2	97.5
Cati	iona						
0	6.000	12.000	32.000	23.000	22.000	5.000	23.000
51	1.910	3.006	10.021	6.103	5.576	1.972	6.514
Ti	0.011	-	-	0.199	0.496	0.001	0.159
<b>Å1</b>	0.181	1.938	5,946	2.518	2.504	0.087	1.868
Čr 👘	· -	-	<b>-</b> .	0.006	-	-	-
Fe2	0.302	1.721	0.006	2.306 .	2.168	0.319	2.060
Mn	0.002	0.046	-	-	0.011	0.018	0.033
Ng	0.645	0.724	-	1.931	2.930	0.685	2.508
Ca	0.905	0.589	2.042	1.935	0.005	0.970	1.869
Na	0.064	-	1.920	0.425 '	0.087	0.063	0.497
K	-	-	0.062	0.450	1.965	-	0.267
Sum	4.020	8.025	19.997	15.874	15.652	4.015	15,775
Inte	r-element ratios						
XFe	0.1629	0.5567				0.1685	
XMg	0.3480	0.2352				0.3620	
XCa	0.4080	0.1913				0.4600	
XMn	0.0012	0.0148			•	0.0095	
An			50.7				
ÅЪ			47.7				
Or			1.5		•		
Mg Na	68.1	29.6		45.6	57.5	68.2	54.9
1	BSOMSP-JC. CPX	2	850MSP-3C, GT	:	3 850MSP-3C, P	LAG	
4	85DHSP-3C, AMPH	5	840HS-51F, 810	ו זנ	6 840MS-51F, C	PX	
7	84DHS-S1F, AMPH						

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MEAN & STD DEVIATION FOR PHASES FROM MAFIC AND ANORTHOSITIC ROCKS

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	. 1	2	3	4	5	6	7
	PLAG	AMPH	PLAG	GT '	91	OL	SPIN
\$102	61.5 +- 1.2	41.9 +- 0.5	59.1 +- 1.5	37.8 +- 0.6	35.6 +- 0.7	39.0 +- 0.9	-
T102	- +- 0.1	2.0 +- 0.3	-	-	5.2 +- 0.4	-	-
A1203	23.9 += 0.7	11.9 +- 0.5	25.4 +- 1.1	20.9 +- 0.4	14.5 +- 0.2	•	58.3 +- 0.3
C+203	•	•	-	-	-	-	2.9
Fe0	0.3 +- 0.9	19.1 ++ 0.5	0.1 +- 0.3	29.8 +- 0.8	21.4 +- 0.4	17.2 +- 0.7	20.5 +- 0.3
MoQ	-	-	-	2.2 +- 0.4	-	0.2 +- 0.3	•
Maß	0.1 +- 0.4	8.7 +- 0.2	-	3.3 +- 0.5	9.8 +- 0.4	42.5 +- 0.3	15.9 +- 0.1
C.a.O.	5.5 +- 0.5	11.6 +- 0.2	7.3 +- 1.2	7.1 +- 0.4	- +- 0.2	-	-
Na20	8.1 += 0.7	1.7 +- 0.6	7.1 +- 0.7	-	0.1 +- 0.4	0.1 +- 0.7	1.0 +- 0.3
K20	0.2 ++ 0.1	1.3 +- 0.1	0.1 +- 0.2	•	9.3 +- 0.2	-	•
Total	99.6	98.1	99.1	100.9	96.0	99.0	98.6
Cation	•						4 000
9	32.000	23.000	32.000	12.000	22.000	4.000	4.000
SL	10.961	6.359	10.627	2.987	5.472	1,000	i.
TL	0.001	0.225	-	•	0.596	•	1 851
A1	5.021	2.125	5.388	1.950	2.624	-	0.062
Cr	•	-	•	-	-		0.463
F#2	0.039	2.422	0.006	1.969	2.753	0.005	-
Mn	-	-	-	0.145	-	1 624	0.637
Hg	0.019	1.974	-	0.387	2.248		-
Ca	1.055	1.880	1.408	0.599	0.007	0 009	0.052
Na	2.811	0.488	2.468	•	0.024	0.000	-
ĸ	0.055	0.250	0.028	•	1.818	3 003	3.068
Sum	19.960	15.723	19.926	8.037	15.341	1.001	21000
Inter-	element ratios						
XFe				0.6333			
XHg				0.1240			
XCa				0.1336			
Xiin				0.0461			
An	26.9		36.1				
AD	1.7		63.2				
0+	1.4	•••	U. (	16.4	44.9	81.5	58.0
Mg No.	32.4	44.9	-	18.4			
1 8	40MS-51F, PLAG	:	2 840HS-1728,	амрн	3 840H5-1728,	PLAG	
4 B	40HS-1728, GT	ļ	5 840MS-1728		6 650HSH-78, 0	DETATUR	
78	SOMSH-70, SPINEL		A-5	7			

MEAN & STO DEVIATION FOR PHASES FROM MAFIC AND ULTRAMAFIC ROCKS

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	1	2	3	4	5		-
\$103	OPX	CPX	AMPH	OPX	CPX	AMON	7
3102	34.U +- 0,6	52.5 +- 0.5	42.2 +- 0.B	53.4 +- 0.5	51.8 +- 1.0	AUCH	81
1102		-	0.8 +- 0.3	• ·	0.1 +- 0.3	1 4 4- 0 4	38.3 +- 0.3
A120.	3 2.6 += 1.1	1.8 +- 0.5	13.4 +- 1.1	2.2 +- 0.1	2.9 +- 0.6	11 4 4- 0.1	4.9 +- 0.2
CF20.		•	0.4 +- 0.3	-	0.5 += 0.3		13.7 +- 0.5
FeO	11.5 +- 0.4	3.8 +- 0.3	7.1 +- 0.3	16.3 +- 0.3	5.5 += 0.7	7.4	0.5 +- 0.2
nn0	0.2 +- 0.4	•	-	0.3 + 0.1	0.1 am 0.7	1.1	7.3 += 0.3
ngū	29.7 +- 0.4	16.5 +- 1.2	15.8 +- 0.7	25.7 +- 0.3	14.3 - 0.7		•
CaO	0.4 +- 0.2	24.0 +- 0.5	12.7 +- 0.2	0.4 +- 0.2	23 0 4- 1 3	13.2	19.0 +- 0.2
Na20	•	0.4 +- 0.6	2.1 +- 0.4	0.2 += 0.7	07 - 02	12.6 +- 0.3	-
K20	-	•	0.9 +- 0.4		-	1.9 += 0.1	0.5 +- 0.8
Tetal	98.4	99.0	95.4	98.6	99.0	1.5 +- 0.1	9.5 +- 0.3
Catio	Da				-		55.1
0	S. 000	6 000					
Si	1.940	1 9//	23.000	6.000	6.000	23.000	22.000
Ti	-	1.344	6.237	1.958	1.932	6.486	5.625
A1	0 111	-	0.092	-	0.004	0.149	0.539
E.		0.016	2.336	0.096	0.127	1.980	2.379
Fa2	· -	•	0.053	-	0.015	0.122	0.058
Ma	0.313	U.118	0.874	0.501	0.174	0.871	0.901
Ma	1.500	-	-	0.010	0.003	-	-
~~ ~~	1.590	0.912	3.489	1.403	0.792	3.325	4.156
N.	0.014	0.951	2.009	0.017	0.921	1.981	-
v	-	0.032	0.602	0.014	0.053	0.526	0.134
м. Б	-	•	0.170 -	-	-	0.271	1.787
JUM	4.005	4.033	15.862	4.000	4.020	15.713	15.579
Inter-	element ratios						
XFe	0.1763	0.0594		0.2593	0 0921		
XMg	0.8138	0.4603		0.7266	0.0321		
XCa	0.0073	0.4803		0.1200 0 0007	0.4132 A 1871		
XMn	0.0026			0.0087	0.9019		
Mg No.	82.2	88.6	80.0	73.7	82.0	79.2	87.7
1 45	0MSH-78 00V	-					
A 85	DHSH_1074 ODV	2	850HSH-78, CPX	3	850MSH-78, PA	LE AMPH	
7 85	OHSH-107A, PHLOG	5	850MSH-107A, CF	YX 6	850MSH-107A,	AMPH	

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MEAN & STD DEVIATION FOR PHASES FROM MAFIC AND ULTRAMAFIC ROCKS ,

	1	2	3	4	5	6	7
\$102	LP C An 1 2	39 04 50 33	UFA 81 56 An 11 22	50 87 An 0 79	FLAU 54 9 4- 1 7	05 0 4m 0 6	43 34 A
T102			0.07	0 76 A. A AG		JJ.J U.B E E A_ A 3	0.12 4
11202	12.0 4. 1.7	31.00 0.04	1 77 - 0.03		-	5.6 +- 0.3	9 67 4
C+203	32.0 ++ 1.7	-	-	-	-	13.3 ** 0.3	0.05 +
E-0	-	27 26 44 0 87	20 04 4- 0 73	11 71	-	16 7 4- 0 4	1.61 ×
Hoß	-	1 07 4- 0.00	0.00 += 0.13	0.10 4- 0.05	_	10.1 +- 0.4	0.07 .
M-O	-		10.00 +- 0.00				18 78 4
11g0	15.0 2.0	6.05 += 0.31	10.08 += 0.37	11.37 ** 0.38		12.4 ** 0.4	22 28 4
Lau N-20	13.9 +- 2.0	6,/9 +- 0.29	0.48 +- 0.09	22.31 +- 0.27	10.7 ++ 1.0		23.30 *
MAZU	2.5 +- 0.1	•	•	U.34 4- U.US	3.4 += 0.3	0.3 += 0.7	0.43 +
K2U 7-1-1	0.1 +- 0.2	-	-	-	0.2 +- 0.1	9.6 +- 0.1	100 30
letel	99.1	101.62	101.16	100.75	38.3	94.4	100.33
Cation	ne '						
0	32,000	12.000	6.000	6.000	32.000	22.000	6.000
Si	8.970	3.006	1.948	1.909	10.005	5.500	1.947
Ti	-	•	0.002	0.010	-	0.645	0.003
A1	6.964	1.933	0.079	0.143	5.956	2.500	0.111
Cr	-	-	-		-	-	0.001
F+2	-	1.762	0.866	0.355	-	2.139	đ. 137
Mn	-	0.070	0.012	0.005	-	-	0.002
Hg	-	0.696	1.064	0.670	-	2.837	0.857
Ca	3.142	0.560	0.019	0.897	2.081	-	0.914
Na	0.931	-	-	0.039	1,897	0.089	0.045
ĸ	0.012	-	-	-	0.053	1.881	-
Sum	20.019	8.027	4.010	4.029	19.992	15.590	4.016
Inter-	element ratios						
XFe		0.5707	0.4474	0.1842			0.0716
XMa		0.2253	0.5370	0.3475			0.4486
XCa		D. 1814	0.0098	0.4656			0.4787
XMn .		0.0226	0.0058	0.0026			0.0011
An	76.9				51.6		
Ab	22.8				47.1		
0r	0.3				1.3		
Mg No.		28.0	54.5	65.4		57.0	86.2
							٠
1 85	SUMSH-107A, PLAG	2	85DMSH-107C.	GT :	8 850MSH-107C.	UFX	
• 85	SUMSH-107C, CPX	5	85DHSH-107C,	PLAG (	850MSH-107C.	BIUT	
7 85	IDMSH-102C, CPX						

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MEA	N & STO DEVIAT	ION FOR PHASES F	FROM ULTRAI	AFIC ROCKS	5			
	1	2		2	4	5	6	7
	OPX	SPI	IN	GT	OL.	NICA	AMPH	OL
S10	2 54.59 +-	1.21 -	- 41	).72 +- 0.9	17 38.77 +- 0.5	1 39.68 +- 0.4	5 42.02 +- 0.13	38.6 +- 0.7
T10	2 0.04 +-	0.05 -	(	).04 +- 0.O	4 0.01 +- 0.0	2 2.63 +- 2.00	1.93 +- 2.16	-
A12	03 2.70 +-	1.26 63.26 +-	- 1.17 2	2.39 +- 0.6	i <b>1 -</b> '	17.04 +- 1.59	14.87 +- 1.15	0.1 +- 0.4
Cr2(	03 0.02 +-	0.05 0.43 +-	0.07 0	1.11 +- 0.0	8 0.01 +- 0.0	3 0.14 +- 0.12	0.13 +- 0.10	-
F+0	13.75 +-	0.86 20.00 +-	1.73 1	1.11 +- 2.3	4 21.93 +- 0.9	18 7.67 +- 0.17	7.91 +- 0.26	21.2 +- 0.3
MnŪ	0.17 +-	0.05 0.06 +-	0.10 0	.63 +- 0.3	2 0.18 +- 0.0	5 0.01 +- 0.05	0.06 +- 0.05	0.2 +- 0.3
MgC	29,20 +-	0.87 16.14 +-	0.68 13	1.16 +- 1.7	5 39.79 +- 0.7	S 20.80 +- 1.00	15.08 +- 0.46	39.0 +- 0.1
CaO	0.29 +-	0.20 0.01 +-	0.04 5	.65 +- 0.7	3 0.01 +- 0.0	2 -	12.18 +- 0.22	-
Na20	0.01 +-	0.02 -		-	-	0.32 +- 0.01	2.55 +- 0.88	•
K20	-	-		-	-	9.09 +- 0.58	1.11 +- 1.60	-
NIO	-	0.08		-	-	-	-	-
ZnO	-	0.25 +-	0.04	-	-	-	-	-
Tota	1 100,77	100,23	100	.81	100.70	97.38	97.84	99.3
Catl	ens							
0	6.000	4.000	12.	000	4.000	22.000	23.000	4.000
Si	1.932	-	3.	006	0.996	5.555	6.087	1.009
71	0.001	-	0.	002	-	8.277	0.210	•
AL	4 0.113	1.944	1.	948	-	2.812	2.539	0.003
C۲	0.001	0.009	0.	006	- 、	0.015	0.015	-
F+2	0.407	0.436	1.	118	0.472	0.898	0.958	0.460
Hn	0.005	0.001	0.	900	0.004	0.001	0.007	0.003
Mg	1.541	0.627	1.	448	1.527	4.341	3.257	1.513
Ca	0.011	-	. 0.	447	-	•	1.891	-
Na	0.001	-	•		•	0.087	0.716	-
ĸ	-	-		-	-	1.624	0.205	•
NL	-	0.002		-	-	-	•	-
Zn	•	0.005	•	-	-	-	-	-
Sum	4.011	3.024	8.	015	3.002	15.610	13.880	5.363
Inter	-element ratio	*						
XFe	0.2073		0.38	63				
XMg	0.7845		0.47	44				
XCa	0.0056		0.14	64				
XMm	0.0026		0.01	29		•		
Mg Ne	<b>b.</b> 79.1	59.0	56	.4	76.4	82.9	77.3	76.7
1	850MSH-102C, 0	IPX	2 85	OMSH-102C,	SPINEL	3 850MSH-102C	GT	
4	850MSH-102C, 0	LIVINE	5 85	DMSH-102C,	PHLOG	6 850MSH-102C.	AMPH	
7	BSOMSR-15, OLI	VINE						

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MEAN & STD DEVIATION FOR PHASES FROM ULTRAMAFIC ROCKS

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		•	3	4	5	8	7
	1	C D Y	BIOT	AMPH	SPIN	51	0L
e. 02	UPX	51.2 44 0.9	37.3	43.1 +- 0.9	0.3 +- 0.1	40,4 +- 0.7	38.2 +- 0.4
3102	34.1 - 1.0	0.6 += 0.3	7.3 += 0.7	2.9 +- 1.4	0.4 +- 1.1	•	•
1102		5.5 += 0.5	14.9 ++ 0.3	13.1 +- 0.3	34.0 +-20.5	22.4 +- O.E	-
A1203	2.3 ++ 4.4	0.9 += 0.5	0.3	0.5 +- 0.1	26.8 +-17.8	0.2 + 0.3	••
LF203	-	55 - 35	7.7 - 0.8	7.3 +- 0.8	29.8 +- 8.2	18.1 +- 1.5	24.7 +- 1.0
reu	13.1 ++ 0.6	3.6 ** 4.4	-	•	0.2 +- 0.6	0.7 +- 0.3	0.2 +- 0.3
	U.1 +- U.4	18 1 44 8 1	17 1 44 8.7	14.8 +- 0.4	7.3 +- 3.4	13.8 +- 1.2	<b>36.8 +- 0.7</b>
ngu	28.4 +- 1.4	15 9 40 7 0	-	11.0 +- 0.3	-	4.3 +- 1.2	-
LAU	0.5 +- 0.9	28 - 20	1.0 += 1.1	3.3 +- 0.5	-	•	-
Nazu	•	2.0 T- 2.0	9 3 an R.1	0.9 +- 0.2	-	-	-
K2U Total	99.2	99.7	94.9	96.9	98.9	99.9	99. <b>Q</b>
Cation	•				4 000	12 000	4.000
6	6.000	6.000	22.000	23.000	4.000	2.000	1.005
51	1.959	1.930	5,426	8.272	0,011	3.003	
Ti	-	0.015	0.804	0,321	0.009	4 608	-
A1	0.098	0.249	2.555	2.247	1.242	1,303	•
Cr	•	0.025	0,035	0.054	0.656	1 122	0.544
F#2	0.393	0.169	0.937	0.885	0.771	1.144	0.000
ňn	0.004	-	-	•	0.005	1 834	1.443
Hg	1.519	0.916	3.719	3.211	0,337	1,364	-
Ca	0.019	0.616	-	1.711	-	U, J44	-
Na	-	0,194	0.282	0.940	•	•	-
ĸ	-	•	1,717	0,173	•	•	1 698
Sum	3.992	4.015	15.474	15.813	3.031	8.010	£.333
Inter-	element ratios					0.3700	
XFe	0.2031	0.1057				0.5024	
XHg	0.7848	0.5094				0.1129	
XCa	0.0099	0.3849				0.0147	
XMn	0.0022				<b>30 A</b>	\$7.8	72.6
Mg No.	79.4	82.8	79.5	78.4	30.4		
1 8	SDMSR-15, DPX		2 850MSR-15, F	PAIM CPX	3 #5DHSR-15,	PHLOG	
4 8	SOMSR-15. AMPH		5 850MSA-15, 0	A-SPINEL	6 850HSR-15.	61	
7 8	SDHSQ-108, OLIVI	NE					

MEAN & STD DEVIATION FOR PHASES FROM ULTRAMAFIC ROCKS

UPX         CPX         GT         AMPH         BIOT         SPIN         SPIN           S102 $53.5 \div 0.7$ $52.1 \div 1.9$ $40.0 \div 0.3$ $41.6 \div 0.5$ $36.6 \div 0.6$ $0.3$ $0.4 \div 0.5$ $102$ - $0.1 \div 0.5$ - $1.4 \div 0.4$ $3.5 \div 0.4$ $1.1 \div 3.3$ - $A1203$ $2.9 \div 0.8$ $3.9 \div 1.1$ $22.4 \div 0.5$ $15.2 \div 0.9$ $16.6 \div 0.7$ $39.5 \div 5.5$ $60.2 \div 0.5$ $Cr203$ $- \div 0.1$ $0.4 \div 0.7$ - $0.1 \div 0.3$ $0.4 \div 0.3$ $21.2 \div 3.0$ $3.1 \div 5.5$ $Cr203$ $- \div 0.1$ $0.4 \div 0.7$ - $0.1 \div 0.3$ $0.4 \div 0.3$ $20.7 \div 2.8$ $22.6 \div 3.5$ $Fe0$ $15.3 \div 0.9$ $5.1 \div 1.1$ $20.5 \div 1.1$ $8.2 \div 0.3$ $8.0 \div 0.3$ $29.7 \div 2.8$ $22.6 \div 5.5$ $60.2 \div 5.5$ $Hn0$ $0.3 \div 0.2$ $22.7 \div 1.3$ $6.1 \div 0.6$ $14.1 \div 0.5$ $18.4 \div 0.6$ $8.2 \div 0.6$ $12.5 \div 0.6$ $Ca0$ $0.3 \div 0.2$ $22.7 \div 0.8$ $  -$ <	Si02 Ti02 A1203 Cr203 F=0 Mn0 Mg0 Ca0	53.5 +- 0.7 - 2.9 +- 0.8 - +- 0.1	52.1 +- 1.9 0.1 +- 0.5 3.9 +- 1.1 0.4 +- 0.7	6T 40.0 +- 0.3 - 22.4 +- 0.5	AHPH 41.6 +- 0.5 1.4 +- 0.4	BIOT 36.6 +~ 0.8 3 5 +- 0 4	SPIN 0.3	SPIN 0.4 +- 0.2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Ti02 A1203 Cr203 F=0 Hn0 Hg0 Ca0	- - 2.9 +- 0.8 - +- 0.1	52.1 +- 1.9 0.1 +- 0.5 3.9 +- 1.1 0.4 +- 0.7	40.0 +- 0.3 - 22.4 +- 0.5	41.6 +- 0.5	36.6 +~ 0.8	0.3	0.4 +- 0.2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	A1203 Cr203 F=0 Mn0 Mg0 Ca0	- 2.9 +- 0.8 - +- 0.1 15 3 0 9	0,1 +- 0.5 3.9 +- 1.1 0,4 +- 0.7	- 22.4 +- 0.5	1.4 +- 0.4	7 4 4 0 4		
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Cr203 F=0 Mn0 Mg0 Ca0	2.9 +- 0.8 - +- 0.1 15 3 0.9	3.9 +- 1.1 0.4 +- 0.7	22.4 +- 0.5		ara 4. Ara	1.1 +- 3.3	-
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	Cr203 F=0 Mn0 Mg0 Ca0	- +- 0.1	0.4 +- 0.7		15.2 +- 0.9	16.6 +- 0.7	39.5 +- 5.5	SO.2 +- 4.4
P=0       15.3 $\leftarrow$ 0.3       5.1 $\leftarrow$ 1.1       20.5 $\leftarrow$ 1.1       8.2 $\leftarrow$ 0.3       8.0 $\leftarrow$ 0.3       29.7 $\leftarrow$ 2.8       22.6 $\leftarrow$ 0.4         Hn0       0.3 $\leftarrow$ 0.2       -       1.2 $\leftarrow$ 0.2       -	HeQ MnQ HgQ CaQ	157		-	0.1 +- 0.3	0.4 +- 0.3	21.2 +- 3.0	J.1 +- 2.7
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Mn0 Mg0 Ca0	10.0 += 0.3	5,1 +- 1,1	20.5 +- 1.1	8.2 +- 0.3	8.0 ++ 0.3	29.7 +- 2.8	22.6 +- 1.0
$ng0$ $25.8 \leftarrow 0.8$ $14.7 \leftarrow 0.6$ $10.1 \leftarrow 0.6$ $14.1 \leftarrow 0.6$ $18.4 \leftarrow 0.6$ $8.2 \leftarrow 0.6$ $13.5 \leftarrow 0.6$ $Ca0$ $0.3 \leftarrow 0.2$ $22.7 \leftarrow 1.3$ $6.1 \leftarrow 0.3$ $12.2 \leftarrow 0.6$ $  -$	ng0 Ca0	0.3 +- 0.2	•	1.2 +- 0.2	<b>-</b> .	-	-	-
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	CaO	26.8 +- 0.8	14.7 +- 0.6	10.1 +- 0.6	14.1 +- 0.6	19.4 +- 0.6	8.2 +- 0.6	13.5 +- 0.6
Ma20       -       0.5 +- 0.8       -       2.0 +- 0.7       0.6 +- 1.7       -       -         K20       -       -       1.1 +- 0.7       9.3 +- 0.1       -       -       -         Total       99.1       99.4       100.4       95.7       93.5       99.9       99.7         Cations       - <td></td> <td>0.3 +~ 0.2</td> <td>22,7 +- 1.3</td> <td>6.1 +- 0.3</td> <td>12.2 +- 0.6</td> <td>-</td> <td>-</td> <td>-</td>		0.3 +~ 0.2	22,7 +- 1.3	6.1 +- 0.3	12.2 +- 0.6	-	-	-
k20       -       -       1.1 +- 0.7 $9.3 +- 0.1$ -       -       -         Total $99.1$ $99.4$ $100.4$ $95.7$ $93.5$ $99.9$ $99.7$ Cations       0 $6.000$ $6.000$ $12.000$ $23.000$ $22.000$ $4.000$ $4.000$ Si $1.941$ $1.922$ $3.010$ $6.143$ $5.402$ $0.009$ $0.011$ Ti       - $0.002$ - $0.156$ $0.394$ $0.025$ -         A1 $0.123$ $0.169$ $1.987$ $2.642$ $2.897$ $1.387$ $1.893$ Cr $0.001$ $0.011$ - $0.012$ $0.047$ $0.499$ $0.0655$ Fe2 $0.454$ $0.157$ $1.289$ $1.010$ $0.988$ $0.740$ $0.505$ Mn $0.009$ - $0.078$ -       -       -       -       -         Mg $1.448$ $0.807$ $1.139$ $3.999$ $4.046$ $0.363$ $0.536$	Na20	-	0.5 +- 0.8	-	2.0 +- 0.7	0.6 +- 1.7	-	-
Total         99.1         99.4         100.4         95.7         93.5         99.9         99.7           Cations         0         6.000         6.000         12.000         23.000         22.000         4.000         4.000           Si         1.941         1.922         3.010         6.143         5.402         0.009         0.011           Ti         -         0.002         -         0.156         0.394         0.025         -           A1         0.123         0.169         1.987         2.642         2.897         1.387         1.893           Cr         0.001         0.011         -         0.012         0.047         0.499         0.055           Fe2         0.454         0.157         1.283         1.010         0.988         0.740         0.505           Mn         0.009         -         0.078         -         -         -         -           Mg         1.448         0.807         1.139         3.099         4.046         0.363         0.536           Ca         0.013         0.899         0.493         1.927         -         -         -         -	K20	-	-	-	1.1 +- 0.7	9.3 +- 0.1	-	-
	Tetal	99.1	99.4	100.4	95.7	93.5	99.9	99.7
0         5.000         5.000         12.000         23.000         22.000         4.000         4.000           Si         1.941         1.922         3.010         6.143         5.402         0.009         0.011           Ti         -         0.002         -         0.156         0.394         0.025         -           A1         0.123         0.169         1.967         2.642         2.897         1.387         1.893           Cr         0.001         0.011         -         0.012         0.047         0.499         0.065           Fe2         0.454         0.157         1.289         1.010         0.988         0.740         0.505           Mn         0.009         -         0.078         -         -         -         -           Mg         1.448         0.807         1.139         3.099         4.046         0.363         0.536           Ca         0.013         0.899         0.493         1.927         -         -         -	Cations							
Si       1.941       1.922       3.010       6.143       5.402       0.009       0.011         Ti       -       0.002       -       0.156       0.394       0.025       -         A1       0.123       0.169       1.987       2.642       2.897       1.387       1.893         Cr       0.001       0.011       -       0.012       0.047       0.499       0.065         F+2       0.464       0.157       1.283       1.010       0.988       0.740       0.505         Mn       0.009       -       0.078       -       -       -       -         Mg       1.448       0.807       1.139       3.099       4.046       0.363       0.536         Ca       0.013       0.899       0.493       1.927       -       -       -	0	6.000	6.000	12,000	23.000	22.000	4.000	4.000
Ti       -       0.002       -       0.156       0.394       0.025       -         A1       0.123       0.169       1.967       2.642       2.897       1.387       1.893         Cr       0.001       0.011       -       0.012       0.047       0.499       0.055         F=2       0.454       0.157       1.283       1.010       0.988       0.740       0.505         Mn       0.009       -       0.078       -       -       -       -         Mg       1.448       0.807       1.139       3.099       4.046       0.363       0.536         Ca       0.013       0.899       0.493       1.927       -       -       -	Si	1.941	1.922	3.010	6.143	5.402	0.009	0.011
A1       0.123       0.169       1.987       2.642       2.897       1.387       1.893         Cr       0.001       0.011       -       0.012       0.047       0.499       0.065         F+2       0.454       0.157       1.289       1.010       0.988       0.740       0.505         Mn       0.009       -       0.078       -       -       -       -         Mg       1.448       0.807       1.139       3.099       4.046       0.363       0.536         Ca       0.013       0.899       0.493       1.927       -       -       -	TL	-	0.002	-	0.156	0.394	0.025	-
Cr         0.001         0.011         -         0.012         0.047         0.499         0.055           F+2         0.454         0.157         1.289         1.010         0.988         0.740         0.505           Mn         0.009         -         0.078         -         -         -         -           Mg         1.448         0.807         1.139         3.099         4.046         0.363         0.536           Ca         0.013         0.899         0.493         1.927         -         -         -	A1	0.123	0.169	1.987	2.642	2.897	1.387	1.893
F+2         0.464         0.157         1.289         1.010         0.988         0.740         0.505           Mn         0.009         -         0.078         -	Cr	0.001	0.011	-	0.012	0.047	0.499	0.065
Mn         0.009         -         0.078         - <th< td=""><td>Fe2</td><td>0.454</td><td>0.157</td><td>1.289</td><td>1.010</td><td>0.988</td><td>0.740</td><td>0.505</td></th<>	Fe2	0.454	0.157	1.289	1.010	0.988	0.740	0.505
Mg         1.449         0.807         1.139         3.099         4.046         0.363         0.536           Ca         0.013         0.699         0.493         1.927         -	Mn	0.009	-	0.078	- `	-	-	-
Ca 0.013 0.899 0.493 1.927	Mg	1.448	0.807	1.139	3.099	4.046	0.363	0.536
No. 0.000 0.000 0.170 -	Ca	0.013	0.899	0.493	1.927	-	-	-
NA - U.038 - U.364 U.172	Na	-	0.038	-	0.564	0.172	-	•
K – – – – – – – – – –	ĸ	-	<b>-</b> '		0.207	1.742	-	-
Sum 3,998 4.005 7,996 15.760 15.689 3.023 3.010	Sum	3,998	4.005	7.996	15.760	15.689	3.023	3.010
Inter-element ratios	Inter-el	element ratios						
XFe 0.2401 0.0845 0.4297	XFe	0.2401	0.0845	0.4297				
XMg 0.7487 0.4329 0.3796	XMg	0.7487	0.4329	0.3796				
XCa 0.0056 0.4826 0.1645	XCa	0.0056	0.4826	0.1645				
XMn 0.0046 0.0251	(Min	0.0046		0.0261				
Mg No. 75.7 83.7 46.9 75.4 80.4 32.9 51.5	ig No.	75.7	83.7	46.9	75.4	80.4	32.9	51.5
1 850M50-108 0PY 2 850M50-108 CPY 3 850M50-108 67		50450-108 084	•	850450-109	PY ·	3 850MS0-109.	67	
	1 850	OMSD-108, AMPU	ے د	RSDMSD-108, 0	HLOG	SOMSD-108	CR-SPINEL	
7 BSDNSD-10B, GREEN SPINL	1 850	and the second						

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HEAN & STO DEVIATION FOR PHASES FROM ULTRAMAFIC ROCKS

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	• 1	2	3	4	5
	PLAG	OPX	AMPH	GT	PLAG
\$10	2 51.5 +- 4.1	50.9 +- 0.3	42.5 +- 1.9	39.1 +- 0.6	54.8 +- 2,4
T10	2 -	-	1.4 +- 1.4	-	•
A12	03 30.1 +- 3.2	3.3 +- 0.6	13.0 +- 0.5	21.5 +- 0.3	28.0 +- 1.5
Fe0	0.1 +- 0.3	23.2 +- 0.6	12.2 +- 0.8	23.9 +- 0.5	-
Mnū	-	0.5 +- 0.1	0.1 +- 0.3	1.3 +- 0.7	-
MgØ	-	20.8 +- 0.6	12.3 +- 0.8	7.4 +- 0.9	-
C=0	13.5 +- 3.5	0.5 +- 0.2	11.5 +- 0.5	7.2 +- 1.5	11.0 +- 2.1
Na20	3.4 +- 2.3	0.3 +- 0.9	2.1 ++ 0.5	-	5.0 +- 1.1
K20	-	-	1.1 +- 0.4	-	0.1 +- 0.2
Tota	1 98.5	99.4	96.2	100.5	90.9
Cati	lons				
0	32.000	6.000	23.000	12.000	32.000
Si	9.464	1.917	6,356	3.007	9,968
Ti	-	-	0.154	-	-
AL	6.533	0.147	2.297	1.952	6.010
Fe2	0.011	0.732	1.526	1.538	•
Hn	-	0.015	0.013	0.083	•
Ng	-	1.170	2.749	0.848	•
Ca	2.661	0.019	1.843	0.591	2.146
Na	1.202	0.020	0.600	-	1.775
ĸ	-	-	0.210	•	CC0.0
Sum	19.871	4.020	15.747	6.018	19.931
Inte	r-element ratios				
XFe		0.3781		0,5027	
XHg		0.6043		0.2771	
XCa		0.0096		0,1932	
XHn		0.0077		0.0270	
An	68.9				54.3
Ab	31.1				44.9
Qr					0.8
Ng Ni	e.	61.5	64.3	35.5	
1	850HSD-108, PLAG	2	85DMSP-2, 0PX	· ·	3 850HSP-2, AMPH
4	BSOMSP-2. GT	5	850MSP-2. PLA	G LATH/MOAT	

MEAN & STO DEVIATION FOR PHASES IN SAPPHIRINE-BEARING SAMPLES

	1	2	3	4	ج ا	e	-
	SAPP	SAPP	SAPP	SAPP	SAPP		( ()
\$102	12.86 +- 0.36	12.90 +- 1.75	11.52 +- 1.32	12.08 +- 0.82	12.09 +- 0.39	0.02 += 0.02	5FIN
T102	0.02 +- 0.03	9.01 +- 0.02	0.02 +- 0.05	0.05 +- 0.04	0.03 += 0.02	0.01 += 0.02	0.01 +- 0.04
A1203	s4.09 +- 0.93	65.18 +- 1.27	66.66 +- 2.16	64.91 +- 0.59	64.90 += 0.91	63 31 4- 2 44	- +- U.UI
Cr203	0.01 +- 0.04	0.21 +- 0.25	0.23 +- 0.36	0.16 +- 0.11	0.04 +- 0.05	0.02 += 0.04	0 20 0 34
F+0	5.90 +÷ 0.76	3.67 +- 0.35	5.14 +- 1.07	6.03 +- 1.51	5.61 Am 1.82	20 49 - 3 04	12.0 -+ 80.0
MnO	0.03 +- 0.03	0.02 +- 0.04	0.03 ++ 0.05	0.07 +- 0.06	0.02 - 0.05	0.02 += 0.02	23.11 +- 1.JU
MgO	17.64 +- 0.57	18.46 +- 0.53	16.98 +- 0.99	17.22 - 0.86	17.66 - 0.45		0.05 ++ 0.06
C=0	0.05 +- 0.05	9.25 +- 0.55	0.08 +- 0.28	0 07 +- 0 07	0.05 += 0.05	0.07 - 0.12	13.00 +- 0,41
Na20	- +- 0.01	0.02 +- 0.04	0.01 +- 0.04	-	- +- 0.03		- +- 0.01
K20	- +- 0.01	-	0.03 +- 0.04	-	0.02	0.04 +- 0.03	u.ui +- u.us
ZnO	-	-	-	-	-	-	0.01 +- 0.04
NiO	-	-	-	-	-	-	1.20
Tatal	100.60	100.72	100.70	100.59	100.40	98.46	99.81
Cation							
0	10.000	10.000	10.000	10 000	10.000	4 000	
Si	0.755	0.749	0.000	0 710	0.000	4.000	+.000
Ti	40.001	-	0.014	0.110	0.001		-
A1	4.434	4.462	4 596	4 500	1 497	1.979	1 977
Cr	-	0.010	0 011	B 007 '	0 002	_	0.009
Fe2	0.290	0.178	0.251	0.297	0.002	0 454	0.000
Ħn	0.001	0.001	0.001	0.003	0.01	0.001	0.333
Hg	1.543	1.598	1.481	1.510	1.548	0.572	0.507
Ca	0.000 -	0.015	0.005	0.004	0.003	0.002	-
Na	-	0.002	0.001	-	•	0.002	0 001
ĸ	- -	•	0.002	-	-	-	-
Zn	•	-	•	-	-	-	0 024
Ni	-	-	•	-	-	<b>_</b> '	0.001
Sum	7.027	7.016	7.024	7.034	7.039	3.011	3.028
Inter-	Element ration						
Mg No.	84.2	90.0	85.5	83,6	84.9	55.8	49.5
1 85	50MSR-3, SAPPHIRIN	E 2	AIDHN-155F. SA	PPHIRINE 3	A10MN-1550 S	PPHIAINE	
4 85	DM-202. SAPPHIAIN		8508-203. SAPPI	ITRINE C	ASOMSON, SPINEL		
		- 4	Contract Swill		concernant at INCC	-	

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7 810HN-155E, SPINEL

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MEAN & STO DEVIATION FOR PHASES IN SAPPHIRINE-BEARING SAMPLES

	1	2	3	4	5	6	7
	SPIN	SPIN	SPIN	GT	, GT	61	GT
S102	0.02 +~ 0.03	0.03 +- 0.03	-	40.51 +- 0.40	39.98 +- 0.25	41.51 +- 0.42	40.68 +- 1.03
T102	0.03 +- 0.01	0.03 +- 0.12	-	0.02 +- 0.06	0.04 +- 0.03	0.04 +- 0.04	0.04 +- 0.07
A1203	61.72 +- 0.59	63.64 +- 0,34	62.65 +- 0.74	22.72 +- 0.41	22.52 +- 0.30	23.34 +- 0.30	23.01 +- 0.39
Cr203	0.62 +~ 0.50	0.37 +- 0.44	•	0.02 +- 0.04	0.01 +- 0.03	0.05 +- 0.09	0.05 +- 0.12
FeQ	19.33 +- 1.34	18.15 +- 1.72	24.33 +- 0.90	18.34 +- 2.73	19.59 +- 0.99	13.76 ++ 1.60	16,54 +- 1.61
MnO	0.04 +- 0.04	0.07 +- 0.01	•	0.30 +- 0.14	0.44 +- 0.10	0.22 +- 0.13	0.29 +- 0.13
MgO	13.01 +- 0.06	15.80 +- 1.02	11.90 +- 0.46	12.71 +- 1.94	10.48 +- 0.30	16.05 +- 0.83	13,39"+- 0.51
Caū	0.04 +~ 0.06	0.09 +- 0.11	-	5.84 +- 4.25	8.26 +- 0.48	6.31 +- 0.26	7.06 +- 0.84
Na20	0.09 +- 0.04	0.03 +- 0.04	0.58 +- 0.19	•	•	-	-
K20	0.04 +- 0.01	-	-	-	-	-	•
Total	94.94	98.21	99.46	100.46	101.32	101.20	101.06
Cations	•						
0	4,000	4.000	4.000	12.000	12.000	12.000	12.000
SL	0.001	0.001	-	3.000	2.978	2,987	2.981
71	0.001	0.001	-	0.001	0.002	0.002	0.002
A1	1,997	1.974	1.977	1.983	1.977	1,979	1,987
Cr	0,013	0.008	• ·	0.001	0.001	0.003	0.003
Fe2	0.444	0.400	0.545	1.136	1.221	0.828	1.014
Mn	0.001	0.002	-	0.019	0.020	0.013	0.010
Mg	0.532	0.620	0.475	1.403	1.164	1.721	1.463
Ca	0,001	0.003	-	0.463	0.659	0.486	0.554
Na	0.005	0.002	0.030	•	-	-	•
ĸ	0.001	•	•	-	•	-	-
Sum	2.997	3.008	3.027	8.007	9.000	0.020	0.022
Inter-e	lement ratios						
XFe				0.3760	0.3974	0.2715	0,3325
XHg				0.4644	0.3789	0.5645	0.4798
XCa				0.1534	0.2147	0.1595	0.1816
XKa				0.0062	0.0090	0.0044	0.0059
Mg No.	54.5	60.8	46.5	55.3	48.8	67.5	59,1
1 810	DMN-155G, SPINEL	2	850M-202, SPI	NEL :	BSDHSR-13A, S	PINEL	
4 850	MSR-3, GT CORE	5	810HN-155E. 61	CORE I	8 810MN-155F, GT	CONE	
7 844							

7 810MS-1356, GT CORE

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MEAN & STO DEVIATION FOR PHASES IN SAPPHIRINE-BEARING SAMPLES

	1	2	Э	4	5	6	7
	67	GT	GT	6T	GT	GT	GT
Si02	40.56 +- 0.33	40.17 +- 0.76	39.75 +- 0.48	40,28 +- 0.70	39.45 +- 0.83	41.00 +- 0.50	40.28 +- 0.71
T102	0.05 +- 0.04	0.02 +- 0.03	•	0.01 +- 0.03	0.02 +- 0.04	0.01 +- 0.03	0.03 +- 0.04
A1203	22.49 +- 0.27	22.85 +- 0,33	22.20 +- 0.49	22.80 +- 0.38	22.24 +- 0.16	23.16 +- 0.37	22.81 +- 0.22
Cr203	0.03 +- 0.04	0.01 +- 0.02	-	- +- 0.02	0.03 +- 0.02	0.06 +- 0.06	0.04 +- 0.09
F+G	17.58 +- 1.05	19.75 +- 1.25	22.30 +- 1.30	19.77 +- 1.65	21.55 +- 0.99	15.73 ++ 1.60	17.85 +- 2.17
Mn0	0.35 +- 0.09	0.33 +- 0.07	0.60 +- 0.40	0.39 +- 0.10	0.72 +- 0.00	0.34 +- 0.13	0.45 ++ 0.23
MgQ	11.93 +- 0.87	13.17 +- 2.32	8.93 +- 0.84	12.95 +- 2.18	9.19 +- 2.44	14.94 +- 1.06	12.16 += 1.41
CaO	7.84 +- 1.51	4.96 +- 2.54	7.30 +- 0.75	4.36 +- 1.73	7.41 +- 2.75	6.02 +- 0.69	6.92 += 1.53
Tetal	100.83	101.26	101.08	100.56	100.61	101.26	100.55
Cation							
0	12.000	12.000	12.000	12.000	12.000	12.000	12.000
\$1	3.001	2.966	2.999	2.989	2.986	2.978	2.987
Ti	0.003	0.001	-	0.001	0.001	0.001	0.002
A1	1.961	1.989	1.974	1.994	1.984	1.983	1.994
Cr	0.002	0.001	•	•	0.002	0.003	0.002
F+2	1.088	1.220	1.407	1.227	1.364	0.956	1.108
Hn	10.022	0.021	0.038	0.025	0.046	0.021	0.028
Mg	1.316	1,450	1.004	1.432	1.037	1.618	1.344
Ca	0.622	0.392	0.590	0.347`	0.601	0.469	0.350
Sum	8.014	8.038	8.014	8.014	8.020	8.028	8.014
Inter-	element ration						
XFe	0.3570	0.3957	0.4629 -	0.4048	0.4475	0.3120	0.3656
XMg	0.4318	0.4703	0.3304	0.4727	0.3402	0.5282	0.4436
XCa	0.2040	0.1273	0.1941	0.1144	0.1972	0.1530	0.1815
XMn	0.0072	0.0067	0.0126	0.0081	0.0151	0.0068	0.0093
Mg No.	54.7	54.3	41.6	53.9	43.2	62.9	54,8
1 8	50M-202, GT CORE	2	850M-203, GT C	:0AE 3	850MSR-13A,	GT CORE	
4 85	50HSR-3, GT RIN	5	810MN-155E, GT	'AIM G	81DMN-155F, G	T RIN	
7 81	IOMN-155G, GT REM						

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MEAN & STO DEVIATION FOR PHASES IN SAPPHIRINE-BEARING SAMPLES

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	1	2	3	4	5	6	7
	GT	6T	61	PLAG	PLAG	PLAG	PLAG
\$102	40.27 +- 0.74	40.29 +- 0.47	39.87 +- 0.45	56.56 +- 1.52	59.78 +- 0.91	57.31 +- 2.95	57.58 +- 2.71
T102	0.04 +- 0.05	0.01 +- 0.02	•	0.01 +- 0.02	t <b>-</b>	0.01 +- 0.04	- +- 0.01
A1203	22.40 +- 0.46	22.85 +- 0.06	22.30 +- 0.38	27.94 +- 1.19	25.03 +- 0.62	27.03 +- 1.51	27.35 +- 1.49
Cr203	0.03 +- 0.06	0.01 +- 0.02	•	- +- 0.01	0.01 +- 0.02	-	0.01 +- 0.05
F=0	19.29 +- 2.52	20.50 +- 2.00	23.67 +- 2.32	0.10 +- 0.11	0.09 +- 0.09	0.11 +- 0.14	0.10 +- 0.12
MnO	0.46 +- 0.10	0.32 +- 0.04	0.68 +- 0.34	0.01 +- 0.04	•	0.01 +- 0.03	- +- 0.03
MgO	11.00 +- 1.34	13.81 +- 1.72	8.92 +- 1.18	-	•	0.04 +- 0.20	0.04 +- 0.24
CaG	7.25 +- 0.96	3.41 +- 0.34	5.25 +- 2.28	10.03 +- 1.38	7.02 +- 1.11	9.03 +- 2.29	9,33 +- 1.88
Na20	-	-	-	6.00 +- 0.84	7.53 +- 1.11	6.42 +- 1.23	6.37 +- 1.04
K20	-	•	-	0.08 +- 0.02	0.19 +- 0.09	0.11 +- 0.13	0.09-+- 0.08
Total	100.74	101.28	101.69	100.73	99.65	100.07	100.87
Catior				,			
0	12.000	12.000	12.000	32.000	32.000	32.000	32.000
Si	3.003	2.971	2,999	10.098	10.696	10.271	10.242
Ti	0.002	0.001	-	0.001	-	0.001	•
A1	1.969	1.986	1.977	5.879	5.279	5.710	5.734
Cr	0.002	0.001	•	-	0.001	•	0.001
F#2	1.203	1.269	1.489	0.015	0.013	0.018	0.015
Mn	0.029	0.020	0.043	0.002	-	0.002	•
Mg	1.223	1.518	1.000	-	-	0.011	0.011
Ca	0.579	0.269	0.504	1.919	1.346	1.734	1.776
Na	-	-	-	2.077	2.612	2.231	2.197
ĸ	-	-	-	0.018	0.043	0.025	0.020
Sum	8.010	8.035	8.012	20.009	19.992	20.001	19.999
Inter-	element ratios						
XFe	0,3965	0,4125	0.4904				
XHg	0.4030	0.4934	0.3294				
XCa	0.1909	0.0876	0.1659				
XMn	0.0096	0.0065	0.0143				
An .				47.8	33.6	43.5	44.5
ÅЬ				51.7	65.3	55.8	55.0
0,				0.5	1.1	0.6	0.5
Mg Ne.	50.4	54.5	40.2			39.3	41.6
1 85	50M-202, GT RIM	2	850M-203, GT F	NIM .	3 BSOMSR-13A.	T RIM	
4 85	SOMSR-3, PLAG	5	810HN-155E, M/	TRIX/EXSOLVED	6 81DHH-155F, 1	ATRIX/EXSOLVED P	rr va

7 BIDHN-155G, MATRIX PLAG

MEAN & STO DEVIATION FOR PHASES IN SAPPHIRINE-BEARING SAMPLES

	1	2	3	4	5	6	7
	PLAG						
\$102	59.45 +- 1.47	57.50 +- 0.75	56.70 +- 2.23	46.66 +- 2.59	54.49 +-10.31	44.74 +-11.72	45.68 4- 1 70
T102	0.01 +- 0.04	-	-	- +- 0.01	-	0.02 ++ 0.05	0.02 += 0.02
A1203	26.06 +- 1.02	26.62 +- 0.98	27.53 +- 1.97	34.30 +- 1.55	28.98 +- 6.28	34.17 +- 7.07	35.15 ++ 0.69
Cr203	-	-	-	0.01 +- 0.03	•	0.02 +- 0.06	0.01 +- 0.02
FeQ	0.31 +- 1.06	-	-	0.08 +- 0.13	0.11 +- 0.04	0.23 +- 0.38	0.13 += 0.12
Kn0	0.01 +- 0.03	-	-	0.01 +- 0.02	0.02 +- 0.06	0.01 +- 0.04	- +- 0.01
Hgû	- +- 0.02	-	-	- +- 0.01	0.01 +- 0.04	0.89 +- 2.47	0.01 ++ 0.02
CaO	7.70 +- 1.17	9.10 +- 0.85	9.83 +~ 2.21	17.71 +- 2.02	11.24 +- 6.99	15.91 +- 3.30	18.53 +- 0.68
Na20	7.14 +- 0.68	6.26 +- 0.66	5.88 +- 0.84	1.61 +- 1.09	5.11 +- 4.45	1.72 +- 3.08	1.07 +~ 0.60
K20	0.27 +- 0.11	•	-	0.01 +- 0.02	0.26 +- 0.23	0.05 +- 0.01	0.01 +~ 0.02
Total	100.95	99.48	99.94	100.39	100.22	97.76	100.61
Cations	•						
0	32.000	32,000	32.000	32.000	32.000	32.000	32.000
51	10.534	10,344	10.176	8.552	9.823	8.411	0.373
τι	0.001	-	•	-	•	0.003	0.003
A1	5.443	5.644	5.824	7.410	6.158	7.571	7.595
Cr	2 -	-	-	0.001	-	B.003	0.001
F+2	0.046	•	- ·	0.012	0.017	a.036	0.020
Ma	0.002	-	-	0.002	0.003	0.002	-
Ng	-	-	-	-	0.003	0.249	0.003
Ca	1.462	1.754	1.890	3.478	2.171	3.205	3.640
Na	2.453	2.184	2.046	0.572	1.786	0.627	0.300
ĸ	0.061	-		0.002	0.060	0.012	0.002
Sum	20.001	19,926	19.936	20.030	20.021	20,119	20.017
Inter-e)	lement ratios						
An	36.8	44.5	48.0	85.8	54.0	83.4	90.5
Ab	61.7	55.5	52.0	14.1	44.5	16.3	9.5
Or	115			0.1	1.5	0.3	0.1
Hg No.					13.9	87.3	12.1

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 85DH-202, MATRIX/EXSOLN PLAG
 2
 85DH-203, MATRIX PLAG
 3
 85DMSR-13A, MATRIX PLAG

 4
 85DMSR-3, PLAG ADJ SAPP/SPIN
 5
 81DMN-155E, PLAG ADJ SP-HUSC
 6
 81DMN-155F, PLAG ADJ SAPP KN075

 7
 85DM-202, PLAG ADJ SAPP/ZOISITE

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MEAN & STO DEVIATION FOR PHASES IN SAPPHIRINE-BEARING SAMPLES

	1	2	3	4	5	6	7
	PLAG	PLAG	CPX	CPX	CPX	CPX	CPX
\$102	46.97 +- 0.81	46.95 +- 0.66	53.01 +- 0.18	51.91 +- 2.32	50.97 +- 0.38	52.36 +- 0.65	50.96 +- 0.34
T102	-	-	0.08 +- 0.07	0.31 +- 0.31	0.30 +- 0.10	0.24 +- 0.15	0.29 +- 0.10
A1203	33.00 +- 1.25	33.13' +- 1.13	1.48 += 1.03	3.82 +- 3.05	8.23 +- 2.02	4.75 +- 2.01	8,24 +- 1.81
Cr203	-	-	-	0.04 +- 0.06	0.03 +- 0.05	0.06 +- 0.07	0.06 +- 0.15
FøØ	-	-	6.75 +- 0.21	6.68 +- 0.37	3.33 ++ 0.33	2.94 ++ 1.15	3,36 +- 0,34
MnQ	-	-	0.11 +- 0.03	0.09 +- 0.06	0.05 +- 0.07	0.04 +- 0.05	0.04 +- 0.07
MgQ	-	•	14.65 +- 0.69	13.96 +- 1.38	13.96 +- 1.93	15.31 +- 0.72	13.84 +- 1.82
CaO	16.90 +- 0.72	17.05 +- 0.84	23.82 +- 0.42	22.73 +- 0.55	22.24 +- 1.18	23.45 +- 0.93	22.24 +- 1.06
Na20	2.20 +- 0.53	2.13 +- 0.53	0.41 +- 0.25	0.88 +- 0.24	1.27 +- 0.62	0.78 +- 0.18	1.31 ++ 0.56
K20	0.13 +- 0.46	0.10 +- 0.40	-	- +- 0.02	0.02 += 0.04	0.02 +- 0.04	0.01 ++ 0.04
Tetal	99.20	99.38	100.31	100.42	100.40	99,96	100.35
Catio							
0	32.000	32.000	6.000	5.000	\$,000	8.000	6.000
Si	8.708	8.691	1.960	1.914	1.846	1,907	1.847
Ti	-	-	0.002	0.009	0.008	0.007	0.008
A1	7.211	7.228	0.065	0.166	0.351	0,204	0.352
Cr	-	-	•	0.001	0.001	0.002	0.002
F+2	-	-	0.209	0.206	0.101	0.090	0.102
Kn	-	-	0.003	0.003	0.002	0.001	0.001
Mg	-	-	0.808	0.767	0.754	0.831	0.748
Ca	3.357	3.302	0.944	0.096	0.863	0.915	0.864
Na	0.791	0.765	0.029	0.063	0.089	0,035	0.045
ĸ	0.031	0.024	•	-	0.001	0.001	
Sum	20.098	20.089	4.020	4.026	4.015	4.012	4.015
Inter-	element ratios						
XFe			0.1063	0,1099	0.0587	0,0407	0.0394
Xrig			0.4113	0.4094	0.4384	U.4323	0.4381
XCa			0.4807	0.4792	0.5020	V. +3#1	U.SUJE
X11n			0.0016	0.0015	0.0009	0,0007	0.0001
An	80.3	81.1					
Ab	18.9	18.3					
0r	0.7	0.6					
Mg No.			79.5	78.8	99.2	1.UK	58.U
1 8	50M-203, PLAG ADJ	SAPP 2	850M-203, PLAG	ADJ SAPP	SOMSR-3, CP		
4 8	DHN-155E, CPX	5	810MN-155F. HI	GH-AL CPX	: 810HN−155F, f	ILXI CPX	

7 810HN-155F, RELICT HIGH-AL CPX

MEAN & STO DEVIATION FOR PHASES IN SAPPHIAINE-BEARING SAMPLES

		1	2	3		4	5	8	7	
		CPX	OPX	OPX	(	DPX	AMPH	AMPH	AHPH	AMPH
SIC	12 51.45	5 +- 2.28	54.12 +- 1.03	54.81 +- 2.	33 55.04	+- 0.22	44.17 +- 2.88	43.68 +- 2.10	45.16 +- 1.43	44.89
110	2 0.41	+- 0.20	0.05 +- 0.03	0.01 +- 0.	03 0.03 4	- 0.07	1.00 +- 0.63	1.13 +~ 0.25	0.39 +- 0.14	1.17
ALZ	03 5.49	) +- 4.35	3.05 +- 2.12	2.32 +- 0.	37 1,64 (	e.0 -+	14.49 +- 4.78	15.46 +- 2.28	11.77 +- 1.45	11.22
Cr2	03 0.07	+- 0.09	0.02 +- 0.04	0.02 +- 0.1	06 0.02 4	- 0,02	0.02 +- 0.09	0.03 +- 0.09	-	0.13
FeQ	5.50	+- 0.62	15.86 +- 2.17	12,30 +- 0.	96 15.63 4	- 0.82	8.79 +- 3.8A	7.93 +~ 0.61	12.75 +- 0.84	12.11
MnO	0.06	+- 0.02	0.09 +- 0.05	0.11 +- 0.1	14 0.18		0.05 +- 0.05	0.04 +- 0.04	0.03 +- 0.10	0.13
MgO	13.47	+- 2.12	27.60 +- 0.54	30.36 +- 0.3	38 28,53 +	- 0.91	14.89 +- 1.20	15.12 +- 0.67	13.27 +- 0.77	13.45
C*0	22.50	+- 0.83	0.21 +- 0.10	0.32 +- 0.3	20 0.27 +	- 0,10	11.67 +- 0.67	11.56 +- 0.51	12.08 ++ 0.31	12.25
Na2	0 1.00	+- 0.43	0.01 +- 0.03	0.04 +- 0.1	10 - +	- 0.01	2.10 +- 0.90	2.30 +- 0.28	1.72 +- 0.43	1.47
K20	-	+- 0.02	- +- 0.02	0.02 +- 0.0	)6 - +	- 0.01	0.52 +- 0.25	0.36 +- 0.20	0.38 +- 0.09	0.94
Cl	-		-	-	-		-	-	•	0.01
Tota	1. 99.95		101.01	100.31	101,34		97.70	97.81	97.55	97.77
Cat	lons									
0	6.000		6.000	6.000	6.000	2	23.000	23.000	23.000	23.000
Si	1.893		1.928	1.937	1.953		6.351	6.255	6.614	6.577
Ti	0.011		0.001	•	0.001		0.108	0.122	0.043	0.129
A1	10.238		0.128	0.097	0.069		2.456	2.610	2.032	1.938
Cr	6.002		0.001	0.001	0.001		0.082	0.003	-	0.015
F+2	0.169		0.472	0.364	0.464		1.057	0.950	1.562	1.484
Mn	0.002		0.003	0,003	0.005		0.006	0.005	0.004	0.016
Mg	0.739		1.465	1.599	1.509		3.192	3.228	2.897	2.937
Ca	0.887		0.008	0.012	0.010	. '	1.798	1.774	1.896	1.923
Na	0.071		0.001	0.003 👕	-		0,586	0.639	0.488	0.418
ĸ	-		-	0.001	-		0.095	0.102	0.071	0.176
C1	-		-	-	-		-	-	-	0.002
Sum	4.012		4.007	4.016	4.012	1!	5.652	15.687	15.607	15.615
Inte	r-element	ratios								
XFe	0.0942		0.2425	0.1838	0.2332					
XHg	0.4111		0.7520	0.0085	0.7589					
XCa	0.4936		0.0041	0.0061	0.0052					
XMn	0.0010		0.0014	0.0017	0.0027		•			
Mg Na	. 81.4		75.6	91.5	76.5	. 7	15.1	17.3	65.0	66.4
1	8504-202,	CPX	2	850MSR-3, 0	PX	3	810HN-155F.	DPX		
4	810MN-1550	, OPX	5	850MSR-3, A	мрн	6	850HSR-3, AM	PH		
7	85DMS8-3,	RET AMPH	8	810HN-155E,	АНРН			•		

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MEAN & STO DEVIATION FOR PHASES IN SAPPHIRINE-BEARING SAMPLES

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	1	2	3	4	5	6	1	
	' AMPH	AMPH	Амрн	Амрн	AMPH	BIOT	BIOT	BIGT
510	2 45.33 += 0.10	47.34 +- 3.15	43.82 +- 1.68	42.54 +- 0.88	44.00 +- 1.	24 39.60 +- 0.57	38.60	38.04
T10	2 1.24 +- 0.52	0.87 +- 0.84	1.93 +- 1.10	0.00 +- 0.29	1.00 +- 0.	25 1.59 + 0.92	4.19	3.42
A12	03 14.01 +- 2.08	11.60 +- 2.84	13.95 +- 1.71	15.83 ++ 0.72	14.26 +- 2.	24 18.78 +- 1,36	18.11	18.09
Cr2(	03 0.07	0.07 +- 0.11	0.09 +- 0.06	0.02 +- 0.07	-	0.01 +- 0.04	0.06	0.05
F+O	5.70 +- 0.98	7.18 +- 0.75	7.45 +- 1.49	8.46 +- 0.50	10.16 +- 0.	39 7.33 +- 1.17	7.34	8.92
Mnû	0.04 +- 0.01	0.04 +- 0.02	0.05 +- 0.01	0.04 +- 0.02	-	0.01 +- 0.06	•	0.03
MgO	16.64 +- 0.31	16.74 +- 0.67	15.22 +- 0.13	14.90 +- 0.13	13.84 +- 8.	88 20,36 +- 0.69	19.38	18.57
CaO	12.40 +- 0.18	12.24 +- 0.40	12.02 +- 0.03	11.42 +- 0.45	11.36 +- 0,	18 0.01 +- 0.03	0.01	•
Na20	2.11 +- 0.21	1.71 +- 0.54	2.06 +- 0.06	2.42 +- 0.10	2.54 +- 0.	30 0.29 +- 0.22	0.20	0.34
K20	0.45 + 0.18	0.35 +- 0.13	1.25 +- 0.18	0.64 +- 0.05	0.39 +- 0.	9 8,26 += 0.79	9.13	8.80
Tota	1 97.99	98.14	97.83	97.07	97.52	96.24	98.99	96.28
Cati	609							
0	23.000	23.000	23.000	23.000	23.000	22.000	22.000	22.000
St	6.412	6.698	6.302	6,169	6,377	5.554	5.423	5.421
Ti	0.132	0.093	0.209	0.087	0.109	0.168	0.440	0.367
A1	2.336	1.934	2.365	2.706	2,436	3.105	2.999	3.039
Cr	0.008	0.008	0.009	0.002	-	0.001	0.007	0.008
F+2	0.674	0.850	0.896	1.028	1.229	0.860	0.862	1.063
Mn	0.005	0.005	0.006	0.005	-	0.001	•	0.004
Mg	3.509	3.530	3.263	3.221	2.990	4.257	4.058	3.945
Ca.	1.879	1.856	1.852	1.774	1.764	0.002	0.002	-
Na	0.579	0.469	0.574	0.680	0.714	0.079	0.054	0.094
ĸ	0.081	0.063	0.223	0,118	0.070	1.479	1.836	1.600
Sum	15.614	15.505	15.705	15.789	15.688	15.504	15,401	15.537
Inter	r-element ratios							
Mg No	o. 83.9	80.6	78.5	75.0	70.9	83.2	82.5	78.8
1	81DHN-155F, AMPH	2	810HN-155G, AH	IPH :	650H-202,	амрн		
4	850H-203, AMPH	5	850MSR-13A. AM	рн (	950MSA-3,	DIOTITE		
7	850H-202, 810111E	8	850M-203, BLOT	116				

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MEAN & STO DEVIATION FOR PHASES IN SAPPHIRINE-BEARING SAMPLES

	1	2	3	4	5	6	7	8	9
	BIOT	SILL	GT	KY	KY	KY	KY	MUSC	HUSC
S102	37.00	37.51 +- 0.52	38.66 +- 0.69	37.28 +- 0.97	37.74	37.66 +- 0.17	37.72	49.69	50.25 +- 1.0
T102	2.25 +- 0.14	0.01 + 0.02	0.02 +- 0.03	0.03 +- 0.04	0.05	0.02 +~ 0.04	0.02	0.02	0.04 +- 0.04
A1203	18.20 +- 0.28	63.71 +- 0.19	22.33 +- 8.34	61.61 +- 5.70	\$3.37	83.55 +~ 0.52	63,39	34.51	37.65 +- 0.82
Cr203	-	- +- 0.01	0.01 +- 0.03	2.17 +- 5.80	0.40	0.13 +- 0.28	0.04	0.02	0.01 +- 0.03
Fe0	9.20 +- 0.57	0.47 +- 0.51	19.59 +- 7.09	0.59 +- 0.44	0.52	0.34 +- 0.12	0,47	0.49	0.23 +- 0.07
MnO	-	0.01 +- 0.02	0.56 +- 0.48	0.01 +- 0.04	0.03	0.01 +- 0.03	-	•	0.06 +- 0.06
HgQ	18.10 +- 0.28	- +- 0.02	8.31 +- 1.98	0.01 +- 0.02	0.03	0.01 +- 0.02	-	0.38	1.08 +- 0.11
CaO	-	0.01 +- 0.04	9.12 +- 4.63	0.01 + 0.03	0.01	0.01 +- 0.02	-	9.63	0.71 +- 1.30
Na20	1.20 +- 0.28	-	-	-	-	-	-	1.40	0.25 +- 0.04
K20	8.55 +- 0.42	-	-	-	0.02	- +- 0.02	-	4.07	6.35 +- 0.27
Total	94.50	101,72	98.60	101.71	102.17	101.73	101.64	100.21	96.63
Cations						•			
0	22.000	5.000	12.000	5.000	5.000	5.000	5.000	22.000	22.000
S1	5.396	0.997	2.977	0.999	1.001	1.001	1,003	6.222	6.352
TL	0.247	-	0.001	0.001	0.001	-	-	0.002	0.004
Al	3.128	1.996	2.026	1.945	1.960	1,990	1.987	5.093	5.610
Cr	4 -	-	0.001	0.046	0.008	0.003	0.001	a.002	0.001
F+2	1.122	0.010	1.261	0.013	0.012	0.008	0.010	0.051	0.024
Ha	-	-	0.037	- `	0.001	-	-	-	0.006
Mg	3.935	-	0.954	-	0.001	-	•	0.071	0.204
Ca	-	-	0.752	-	-	-	•	1.292	0.096
Na	0.339	-	-	-	-	-	-	0.340	0.061
ĸ	1.591	-		•	0.001	-	-	0.650	1.024
Sum	15.758	3.005	8.009	3.005 .	3.004	3.002	3.002	13.724	13.382
Inter-elo	ement ratios								
XFe			0.4199						
XHg			0.3175						
XCa	•		0.2505						
XHn			0.0122						
Mg No.	77.8		43.1	2.9	5,3	5.0		58.0	69.J
1 85	50MSA-13A, BIOTI	TE	2 850HSR-3, AL	.SIL	3 850	NSR3, GT ASSOC W	ITH CPX		
4 81	IDHN-155E, ALSIL	. !	S 810MN-155F,	ALSIL	6 81D	HN-155G, ALSIL			
7 85	50H-202, ALSIL		850MN-155E,	MUSC	9 810	MN-155G, MICA			

MEAN & STD DEVIATION FOR PHASES IN SAPPHIRINE-BEARING SAMPLES

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	1	2	3	4	
	MUSC	RUT	RUT	EPIO	
\$102	47.10	-	0.01	37.52 +- 0.54	
T 102	-	100.33	99.95	0.14	
A1203	34.70	-	0.01	27.40 +- 0.35	
Cr203	-	0.26	0.07	0.01 +- 0.03	
F+0	0.70	0.11	-	4.38 +- 0.14	
MnQ	-	-	0.09	0.03 +- 0.01	
MgD	0.70	-	-	0.81 +- 0.13	
CaO	-	-	-	20.82	
Na20	•	-	0.05	-	
K20	11.70	-	-	-	
Total	94.90	100.70	100.18	91.11	
Cations					
0	22.000	2.000	2.000	13.000	
SL	6.294	-	-	3.232	
Ti	-	0.997	0.996	0.009	
A1	5.465	•	-	2.782	
Cr	-	0.003	0.001	0.001	
F+2	0.078	0.001	-	0,316	
Mn	-	-	0.001	0.002	
Mg	0.139	-	-	0.104	
Ca	-	-	-	1.922	
Na	-	-	0.001	-	
x	1.995	-	-	-	
Sum	13.971	1,001	1.002	8,367	
Hg No.	64.1			24.0	
1 85DHSA	-134, HUS	ic a	8100	-155G, AUTILE	

-				
3	USOM-202,	AUTILE	 850M-202,	ZOISITE

# APPENDIX IV - Mineral recalculation techniques

This appendix summarises the mineral recalculation schemes for determination of ferric iron and assignment of site occupancies.

### PYROXENE

Ferric iron was determined by the charge balance method of Ryburn et al. (1976) and the resulting compositions recalculated into end-member phase components following Cawthorn & Collerson (1974) and quadrilateral components after Lindsley (1983). The site occupancies were assigned according to the general formula  $X_{1-p}Y_{1+p}Z_{2}O_{6}$  (01) where X represents Na, Ca,  $Mn^{2+}$ ,  $Fe^{2+}$ , Mg in the 6 and 8 coordinated M2 site; Y represents  $Mn^{2+}$ ,  $Fe^{2+}$ , Mg,  $Fe^{3+}$ , Al,  $Cr^{3+}$  and Ti in the octahedral M1 site; Z represents Si and Al in the tetrahedral site.

#### AMPHIBOLE

Amphiboles have been recalculated to include  $Fe^{3+}$  on the basis of 23(0), following Papike et al. (1974). This scheme takes the mid-point of maximum and minimum (zero) ferric iron determinations; the minimum  $Fe^{3+}$  typically resulting in greater than 23(0) whereas, the maximum increases the amount of Na in the M4 site. The compositions have been assigned to site occupancies according to the general formula  $A_{0-1}B_2C_5T_8$  (OH,F,Cl)<sub>2</sub> where A = Na,K in 10-12 coordination;  $B(M4) = Na,Ca,Mn,Fe^{2+},Mg$  in 6-8 coordination;  $C = Mg,Fe^{3+},Fe^{2+},Mn,Al,Ti$  in 6-coordination; T = Si,Al in tetrahedral coordination.

#### GARNET

The analyses were recalculated to include ferric iron by charge balance and assigned to end-members following Rickwood (1968).

## OPAQUE OXIDES

The ferric iron in Mt-Usp was obtained from the charge balance technique of Carmichael (1967) and then recalculated into end-members phase components following Powell & Powell (1977).

# THERMODYNAMIC ABBREVIATIONS

a, - activity of component i f - volume factor G - Gibb's Free energy K - equilibrium constant μ - chemical potential V, - stoichiometric coefficient for component i n, - no. of moles of component i P - pressure S - entropy R - gas constant T - temperature t - time V - volume  $\overline{V}$  - molar volume  $X_i$  - mole fraction of component i  $(\partial X_i)$  - partial differential with respect to fixed parametrs a,b. W - mixing parameter (Margules)

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