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MINERALOGY AND OXYGEN ISOTOPE COMPOSITION OF THE BOEHLS
BUTTE ANORTHOSITE, NORTHERN IDAHO

A Thesis
Presented for the
Master of Science
Degree
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Abstract

The Boehls Butte Anorthosite (BBA), exposed in northern Idaho differs mineralogically, texturally, and geochemically from most Proterozoic massif anorthosites. As a result, a clear understanding of its origin and subsequent history has been prevented. Several origins have been proposed for this unique anorthosite, including metasomatism (Hietanen, 1963), partial melting of aluminous metasediments plus superimposed hydrothermal alteration/metasomatism (Nord, 1973), subsolidus exsolution and shear differentiation (Juras, 1974), and igneous intrusion with assimilation and mass transfer at the contact (Goldberg, 1983).

Based on careful petrography and electron microprobe analyses, three varieties of BBA have been identified, including massive, sheared, and foliated varieties. In addition, plagioclase (+/-quartz) veins which cross-cut the anorthosite have also been identified. The most distinguishing mineralogical characteristic of massive BBA is andesine (An₃₄₋₄₈) megacrysts (up to 20 mm) with anorthite (An₈₂₋₉₈) inclusions. Sheared anorthosite is characterized by grain size reduction, with no change in composition relative to massive anorthosite. Alternating layers of anorthite laminae and medium andesine grains, as well as biotite and hornblende elongation, define the foliation in foliated BBA. Plagioclase (+/-quartz) veins, not inferred to be part of the

anorthosite, are andesine or oligoclase + quartz in composition.

Stable isotope analyses of plagioclase separates (andesine and anorthite) indicate that a complex meteoric-hydrothermal event affected the BBA after crystallization, and can be used to address previously proposed hypotheses for the origin of the unique mineralogy and texture of the BBA. A wide range of $\delta^{18}\text{O}$ "whole-plagioclase" (wp) values occur in massive BBA, from -6.2 to 6.1‰ (SMOW). Sheared BBA retains low, less variable isotopic compositions of -5.8 to 1.7‰. Foliated BBA retains oxygen isotopic signatures of 5.0 to 6.0‰, consistent with most igneous anorthosites. Calculated oxygen isotope fractionations between andesine-anorthite at peak metamorphic temperatures (650-750°C; Grover et al, 1992) range from $\Delta^{18}\text{O} = 0.5$ to 0.6‰. These values are observed more frequently in sheared and foliated samples than in massive anorthosite samples.

Petrographic and isotopic data are not consistent with any of the proposed hypotheses for the formation of the BBA. Exsolution and shear differentiation, proposed by Juras (1974), cannot be ruled out entirely. However, this hypothesis remains problematic. The size of the plagioclase intergrowths known to occur are on the micron scale (or less), whereas the intergrowths within the BBA are many orders of magnitude coarser (on the mm scale). Shear differentiation seems unlikely, as the shear strengths of andesine and

anorthite are very similar.

Leaching of Na and Si by a high temperature hydrothermal fluid, leaving a plagioclase phase that is enriched in Ca and Al, is an alternative hypothesis which might explain the occurrence of andesine megacrysts containing anorthite inclusions and of anorthite-rich laminae. Anorthite is ^{18}O -depleted relative to andesine, suggesting that the laminae may have been the focus of fluid flow. Some of the most ^{18}O -depleted samples have apparent equilibrium (M2) $\Delta^{18}\text{O}$ values, suggesting that fluid-flow within these samples occurred just after the peak of metamorphism and while the rocks remained at elevated temperatures.

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LIST OF ABBREVIATIONS

Minerals

Albite.....	Ab
Amphibole.....	Amph
Anorthite.....	An
Biotite.....	Bt
Chlorite.....	Chl
Garnet.....	Grt
Hornblende.....	Hbl
Muscovite.....	Ms
Quartz.....	Qtz

Sample Locations

Boehls Butte.....	BB
Little Goat Mountain.....	LGM
Monumental Buttes.....	MB

Other

Boehls Butte Anorthosite.....	BBA
Inclusion.....	Inc
Laminae.....	Lam
Megacryst.....	Mega
Rare Earth Element.....	REE
Whole-plagioclase.....	wp
Whole-rock.....	wr

I. INTRODUCTION

The Boehls Butte Anorthosite:

an unusual Proterozoic anorthosite

Massif anorthosites are igneous rocks containing 90 percent or more plagioclase feldspar (andesine and labradorite, An₅₀ +/-10), orthopyroxene, and sometimes olivine and augite. Other mafic minerals may include hypersthene, magnetite, and ilmenite. Texturally, the plagioclase grains are subhedral to euhedral with weak to normal oscillatory zoning (Weibe, 1980). Massif anorthosites are generally Proterozoic, ranging in age from 1700 My to 1200 y (Morse, 1982) and they typically intrude Proterozoic gneisses that have previously undergone a high degree of metamorphism and deformation (Emslie, 1985). Anorthosites are often spatially associated with rocks of gabbroic, granitic, and syenitic compositions, or charnockites (Hietanen, 1963).

Geochemically, Proterozoic massif anorthosites are characterized by large positive europium anomalies, small initial strontium isotopic ratios, and large K/Rb ratios (Goldberg, 1983). Oxygen isotope compositions of unmetamorphosed massif anorthosites typically range from $\delta^{18}\text{O}$ of 5.8 to 7.6 ‰ SMOW; metamorphosed anorthosites show somewhat greater variation, 8.9 to 11.2 ‰ (Taylor, 1969).

The Proterozoic Boehls Butte anorthosite (BBA) possesses many differences from most Proterozoic massif anorthosites. The major characteristic that sets the BBA apart is its unique

mineralogy. Two- or three- compositionally-distinct plagioclase phases (andesine, An₃₄₋₄₈; labradorite, An₅₁₋₆₅; and bytownite-anorthite, An₈₂₋₉₈) occur within the anorthosite. Bytownite-anorthite will be referred to as "anorthite" through the remainder of this thesis except when another researcher's work is being cited. Large (up to 20 mm), anhedral, andesine megacrysts with optically continuous anorthite inclusions is the most distinctive feature of the BBA. The anorthosite is nearly devoid of mafic minerals, containing less than 5% hornblende and/or biotite, with minor garnet, epidote, chlorite, and ilmenite; pyroxene is absent.

BBA retains oxygen isotopic compositions with a much broader range than measured in other Proterozoic massif anorthosites. Stable isotope analyses of the BBA "whole plagioclase" (ie. undifferentiated plagioclase removed from mafic minerals) range from $\delta^{18}\text{O}$ (SMOW) = -5.9 to 10.1 ‰ (Taylor, 1969; Mora and Valley, 1988a).

The BBA is rich in aluminum (>29 wt.%), calcium (>11 wt.%) and strontium (>450 ppm) and possesses low abundances of K, Rb, Hf, Th, and U (Goldberg, 1983). It possesses among the smallest values observed in Proterozoic anorthosite massifs for the transition elements Sc, Cr, Co and Ni, commonly less than 1 ppm (Papezik, 1965; Isachsen and Moxham, 1969). K/Rb ratios of approximately 400 are also relatively low (Reynolds et al., 1969). The BBA is light REE enriched and exhibits large positive Eu anomalies, nearly identical to

other Proterozoic anorthosites (Simmons and Hanson, 1978, Ashwal and Seifert, 1980; Goldberg, 1983). $^{87}\text{Sr}/^{86}\text{Sr}$ ratios from massive BBA average 0.7046 (Heath and Fairbairn, 1969) and are consistent with values observed within other anorthosite massifs (Goldberg, 1983).

The BBA is not associated with gabbroic, granitic, syenitic rocks or charnockites which commonly occur with massif anorthosites (Hietanen, 1963). Instead, the BBA occurs interlayered with and surrounded by aluminous, Mg-rich pelitic schist (Hietanen, 1963; Carey et al., 1992).

Hypotheses for the Origin of the BBA

The unusual features of the BBA; its unique mineralogy, geochemistry and texture, have prevented a clear understanding of its origin and, as a result, several hypotheses have been proposed. Proposed origins include metasomatism (Hietanen, 1963), partial melting of aluminous metasediments plus superimposed hydrothermal alteration/metasomatism (Nord, 1973), shear differentiation (Juras, 1974), and igneous intrusion with assimilation and mass transfer at the contact (Goldberg, 1983).

Although it is generally agreed that anorthosites are of igneous origin, a number of researchers have questioned such an origin for the BBA (Hietanen, 1963, Nord, 1973), because the bimodal assemblage is difficult to explain from simple crystallization of a melt or known plagioclase subsolidus

relationships.

Hietanen (1963) proposed that a calcic plagioclase anorthosite was created by migration of Al from an aluminum-rich shale into limestone, and that calcic plagioclase was altered by metasomatism to produce andesine. Evidence for a metasomatic origin for the BBA includes the distinct layering, the abundances of aluminum silicates, and the presence of layers and lenses of bytownite anorthosite interbedded with schist (Hietanen, 1963, 1984). However, this concept, also referred to as granitization, is not currently accepted.

Hietanen later proposed a separate origin for the massive anorthosite, retaining her original proposal for the foliated anorthosite bodies. Due to the Carlsbad twinning of some plagioclase megacrysts, typically an igneous phenomenon, Hietanen proposed crystallization of labradorite from a melt created by partial melting of metasedimentary rocks. Aluminum silicate remnants sometimes occur as inclusions within the megacrysts (Hietanen, 1984), where Ca from the rims of the megacrysts combined with Al and Si to form anorthite shells around the remnants.

Based on textural evidence, Nord (1973) proposed a separate origin for each plagioclase phase. In massive anorthosite, the labradorite was proposed to have originated from partial melting of an anorthite-rich metamorphic rock, with the anorthite being a refractory phase during the partial melting. Reaction with a later hydrothermal fluid resulted in

replacement of labradorite and anorthite by andesine. Anorthite inclusions remain in andesine megacrysts because anorthite was less reactive with the hydrothermal fluid than labradorite. Evidence that andesine was a hydrothermal phase includes the presence of cross-cutting andesine-quartz veins in the surrounding schist and the presence of fluid inclusions exclusively in andesine megacrysts. Nord proposed that foliated anorthosite was formed from anorthite-rich metasediments which experienced the hydrothermal andesine forming event (1973).

Juras (1974) proposed that a labradoritic anorthosite solidified from a magma. Subsolidus exsolution of anorthite from labradorite resulted in the common bimodal assemblage of andesine and anorthite. Intense shearing, occurring during amphibolite facies metamorphism, mechanically differentiated this rock to produce alternating layers of anorthite and andesine. This hypothesis of shear differentiation is based on textural and petrofabric analysis.

The plagioclase solid solution series is complicated by the varying Al/Si ratio from albite ($\text{NaAlSi}_3\text{O}_8$) to anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$), leading to complex solid solution relationships. Intergrowths that may occur in plagioclase include peristerite, Boggild and Huttenlocher intergrowths (Smith and Brown, 1988). The peristerite intergrowth occurs in rocks of bulk composition from An₂₋₁₆, Boggild from An₄₃₋₅₈, and Huttenlocher from An₆₇₋₉₀ (Smith and Brown, 1988). Juras

(1974) concluded that anorthite inclusions and lamellae exsolved from labradorite to produce an andesine host. This hypothesis is problematic because of the tendency of the plagioclase intergrowths to be submicroscopic or just visible optically (Smith and Brown, 1988). Anorthite inclusions within andesine in massive BBA are markedly coarser than previously described plagioclase intergrowths (<0.5 mm maximum dimension).

Based on the sharp contact between foliated anorthosite and schist, Goldberg (1983) proposed that a magmatic anorthosite intruded sedimentary country rocks (Precambrian argillites). Assimilation and mass transfer at the contact is thought to explain the complex aluminous zone in the country rocks. However, geochemical trends observed within the anorthosite contact zone are not characteristic of metasomatism. Instead, geochemical analyses of the BBA are indicative of magmatic crystallization. Plagioclase/liquid partition coefficient data was used by Goldberg (1983) to constrain the composition of the magma from which the BBA crystallized; the data were consistent with a broad range of basaltic rock types.

Finally, Carey et al. (1992) reviewed available literature and proposed that the BBA originated by magmatic crystallization, and was associated with lit-par-lit injection and partial assimilation of country rocks. Partial melting of contact rocks created an Al- and Mg- rich restite surrounding

the anorthosite. They argue that unmixing of labradorite to andesine and anorthite during metamorphism and deformation caused recrystallization of plagioclase and resulted in a foliated anorthosite.

Statement of Problem

Because the origin of the BBA remains enigmatic, a detailed mineralogical, petrographical, and geochemical analysis is necessary to better determine the origin and geologic history of this unusual anorthosite. The BBA is most likely of igneous origin, but apparently has been subjected to several post-crystallization events including two episodes of regional metamorphism, uplift, nearly isothermal decompression, and fluid-rock interaction, resulting in a very complex composition, texture and stable isotope geochemistry. By characterizing the unique features of the BBA, we may begin to understand better these different events and their effect on the anorthosite.

An understanding of the complex textural relationships of the plagioclases is necessary to help resolve the longstanding controversy over the origin of the unique mineralogy and texture of the BBA. Nord (1973) reports partial electron microprobe analyses of the plagioclases; none of the other previous studies reports detailed mineral compositions. Electron microprobe analyses combined with careful petrography and cathodoluminescence may help to:

1. determine the composition of the different plagioclases occurring in different textural combinations within the BBA,
2. identify different textural varieties of BBA occurring throughout the anorthosite body,
3. determine the composition of the plagioclases exhibiting features such as subgrain formation, diffusion, and possible pathways of fluid flow which may only be visible using cathodoluminescence petrography.

Complete electron microprobe analyses of the plagioclases, as well as hornblende, garnet, chlorite, and micas occurring in anorthosite are included in this thesis (Appendix A-H).

The BBA yields unusual whole-rock $\delta^{18}\text{O}$ and whole-plagioclase $\delta^{18}\text{O}$ values, differing from those of unmetamorphosed Proterozoic anorthosites. Additional isotope analyses, such as those of plagioclase separates may help to:

1. determine whether the plagioclases are in isotopic equilibrium,
2. characterize the nature of fluid flow on a small scale, within hand sample,
3. using isotopic fractionations, determine the timing and composition of the fluid with which the BBA may have interacted since crystallization.

A combination of detailed petrography, electron microprobe analyses, cathodoluminescence, and stable isotope

geochemistry will be used to interpret the geologic history of the BBA, and ultimately, the origin of its unique mineralogy and texture.

II. GEOLOGIC HISTORY AND SETTING

The Boehls Butte Formation

Approximately 30 km north of the Idaho batholith, the rocks of the Precambrian Belt Group are interrupted by an uplifted block of re-Belt Group rocks, the Boehls Butte (BB) Formation. North- and east-southeast trending faults and igneous masses separate the BB Formation from the lower Belt Group rocks (Figure 1, from Carey et al., 1992). Lithologies included in the BB Formation are quartzite, aluminous schist, garnet amphibolite, and the Boehls Butte anorthosite (BBA). U-Pb ages of BBA and surrounding schist are reported as 1625 and 1665 My, respectively (Reid et al., 1973).

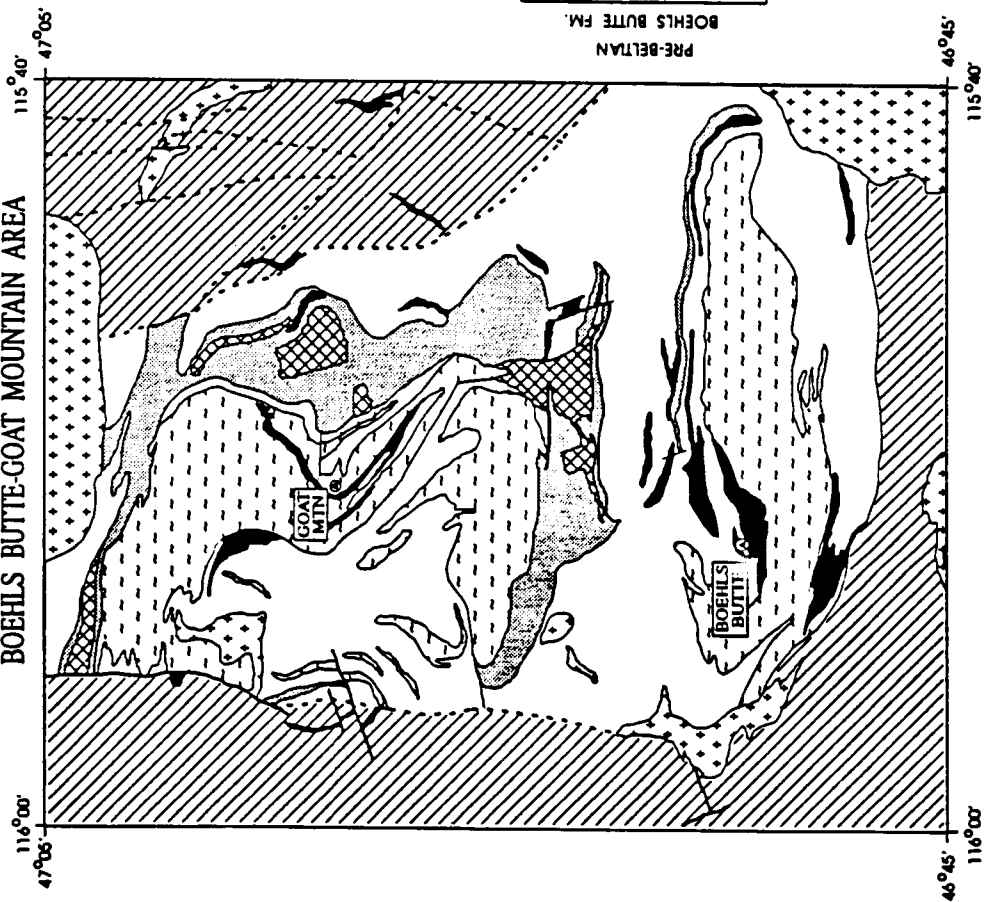
The Orphan Point Fault separates the schist of the BB Formation from the schist of the Prichard Formation of the Belt Group. Although both are musc-bt-gt schists (Hietanen, 1984), they can be differentiated. The Prichard schist is coarse- to medium-grained with fine- to medium-grained interlayers rich in quartz and plagioclase. Kyanite occurs locally in the north and sillimanite occurs in the south of the Prichard schist (Hietanen, 1984). The highly Al- and Mg-rich, coarse-grained musc-bt-gt schist of the BB Formation contains plagioclase (An₂₅₋₄₅) as well as all three aluminum silicate polymorphs (kyanite, andalusite, and sillimanite). The proportion of plagioclase and the An content within the schist increases toward the BBA (Hietanen, 1984).

The BBA forms a double-crested anticline that dips to the

Figure 1: Map of the Boehls Butte Formation.

From Carey, J.W., Rice, J.M., Grover, T.W. (1992)
Petrology of aluminous schist in the Boehls Butte region of
northern Idaho: geologic history and aluminum silicate phase
relations. American Journal of Science, 292.

GENERAL GEOLOGIC MAP OF THE BOEHLS BUTTE-GOAT MOUNTAIN AREA



EXPLANATION

PRE-BELTAN BOEHLS BUTTE FM.		BOEHLS BUTTE ANORTHOSITE
		BOEHLS BUTTE QUARTZITE
		BOEHLS BUTTE SCHIST
		UNDIFFERENTIATED BELT METASEDIMENTARY ROCKS
		AMPHIBOLITE
CRETACEOUS TO TERTIARY		PYROXENE GABBRO
		IDAHO BATHOLITH AND RELATED PLUTONIC ROCKS

southeast (Hietanen, 1984). Layer and lens-like masses of anorthosite are interlayered with aluminosilicate-rich schist and occur over an approximate area of 100km². Coarse-grained massive anorthosite dominates the northern body, whereas layered/foliated anorthosite occurs in the middle and southern anorthosite bodies (Hietanen, 1984). The focus of this study is on the northern and middle bodies because much of the exposure of the southern body is now below water as a result of construction of the Dworshak Dam.

Regional Metamorphism

Two episodes of regional metamorphism have been documented in the study area, resulting in a complex metamorphic terrain. The first metamorphic event, M1, was Barrovian (Carey et al., 1992), and produced a strong foliation and large porphyroblastic minerals in the Snow Peak area, northeast of BB (Lang and Rice, 1985a). Relict isograds mapped by coarse-grained muscovite pseudomorphs after kyanite and staurolite indicate that the metamorphic grades increase to the south, toward the Idaho batholith (Lang and Rice, 1985a). Although radiometric dates are inconclusive, M1 may be associated with large scale thrusting and crustal thickening in the Sevier Hinterland (Skipp, 1987, Carey et al., 1992).

M2, also Barrovian, grades from biotite to sillimanite zone. This metamorphic event resulted in almost complete

re-equilibration of M1 minerals to M2 minerals (Carey et al., 1992). Peak temperatures of this predominantly thermal metamorphic event exceed 700°C (650-750°C) and pressures reached 8kb (8-11 kb) in the BB Formation. In the Belt Rocks of the Snow Peak area, temperatures and pressures ranged from <450°C and 4.5 kb in the biotite zone to >560°C and 6 kb in the kyanite zone (Lang and Rice, 1985b). Concentric isograds around and increasing in grade toward the Idaho batholith suggest that the metamorphic event was contemporaneous with the intrusion of the Idaho batholith which is late Cretaceous to early Tertiary in age (Grover et al., 1992).

The metamorphic peak of M2 was immediately followed by uplift of the BB Formation. This uplift resulted in nearly isothermal decompression (to $P = 4-6$ kb) and recrystallization of mineral assemblages in the BB schist, resulting in the inversion of strained kyanite to andalusite (Carey et al., 1992). Sillimanite (fibrolite) occurs rimming kyanite or andalusite or as overgrowths on both kyanite or andalusite (Carey et al., 1992). Preliminary stable isotope data (Mora and Valley, 1988a, 1991) suggest that channelized, retrograde meteoric-hydrothermal fluid-rock interaction was superimposed on the BBA and surrounding regionally metamorphosed Belt Group rocks.

III. METHODOLOGY

Thin sections of anorthosite collected from Little Goat Mountain and Monumental Buttes (Figure 1) were examined petrographically, paying particular attention to plagioclase mineralogy and the different combinations with which the plagioclases occur. Based on those criteria, several varieties of anorthosite were identified; these are summarized in the following chapter. Thin sections were point counted (1000 points per thin section) for modal analyses; modes are listed in Table 1. Because only a few samples contain labradorite and, where present, it typically composes only a minor amount (<10% of the sample), only two plagioclase phases, andesine and anorthite, were point-counted. Grains which could not clearly identified as andesine or anorthite were not counted. Plagioclase, amphibole, biotite, garnet, and chlorite were analyzed by wavelength dispersive analysis on the Cameca SX-50 electron microprobe at the University of Tennessee. These analyses are reported in Appendices A-H. Energy dispersive analysis was used to qualitatively evaluate the composition of other minerals present in the anorthosite: zoisite, epidote, kyanite, and quartz. All phases were analyzed using an accelerating voltage of 15kV and a beam current of 20nA. A counting time of 20 seconds and a beam size of 5um was maintained. A ZAF correction program was used to make matrix corrections.

Table 1: Mineral Assemblages and Modes

SAMPLE	An30-50	An80-100	Amph	Chl	Bt	Ms	Qtz	Grt	other
MASSIVE ANORTHOSITE									
83LGM122	38.5	21.7	35.8	0.8	0.5	1.5			1.2
83LGM123	69.6	21.0	0.1	3.7		4.9			0.7
83MB15	62.7	29.3	6.7	0.8					0.5
83MB45	65.5	29.4	3.5				0.9		0.7
84LGM121	X	X	X	X	X		X		
86MB6A	61.4	31.8	5.2	1.1					0.5
86MB6B	55.9	26.1	14.3	1.5	0.5	1.5			0.2
90LGM19	X	X	X	X	X				
90LGM37A	X	X	X	X					
90LGM39	46.4	36.0	14.9	2.3				0.4	
90MB44	X	X	X		X			X	
90MB46	X	X	X	X					
90MB64	X	X	X						
880-645	X	X	X	X	X				
83MB18	52.2	39.3	6.7	0.8					1.0
83MB31	75.3	21.1	0.3	2.6	0.2	0.4			0.1
83LGM57	X	X	X						
83LGM124	52.4	43.3	3.0	0.2		0.8			0.3
84LGM123	X	X	X						
90LGM36	X	X	X	X					
90LGM37B	X	X							

X = present

Table 1: (cont.)

SAMPLE	An30 -50	An80 -100	Amp h	Chl	Bt	Ms	Qtz	Grt	oth er
SHEARED ANORTHOSITE									
90LGM18A	X	X		X					
90LGM18B	X	X							
90LGM18C	X	X		X					X
90LGM18D	X	X	X					X	X
90LGM18E	X	X							X
FOLIATED ANORTHOSITE									
83LGM69	X	X	X	X					X
83LGM70	62.3	19.6		2.7				13.6	1.8
83LGM71	71.8	15.9			11.1				1.2
83LGM125	X	X							X
PLAGIOCLASE (+/- QUARTZ) VEINS									
	An30	An20							
83MB33	97.9			2.0					0.1
83MB38		88.2	0.1	1.7			9.6		0.4

X = present

Fourteen samples of anorthosite for which electron-microprobe and petrographic data were obtained, and for which "whole-plagioclase" (mafic phases removed from plagioclase) isotopic compositions had been previously determined (Mora and Valley, 1988a) were selected for detailed isotopic analysis. Mafic phases were magnetically removed from the crushed (60-100 mesh) whole-rock samples. Plagioclase grains were then ground to 80-120 mesh to ensure that no composite grains remained. Coexisting plagioclases were gravimetrically separated using Lithium metatungstate, diluted to two solutions (SG = 2.74 mg/l and SG = 2.70 mg/l). This enabled the andesine as well as the anorthite to be separated. The proficiency of the separation procedure was checked optically, using refractive indices and immersions oils. The separates were determined to be 99% pure.

Oxygen was extracted from plagioclase separates using Bromine Pentafluoride (BrF_5) (Clayton and Mayeda, 1963) and converted to carbon dioxide (CO_2) using hot graphite. Isotopic ratios were analyzed on the VG Micromass 903 mass spectrometer at the University of Tennessee. Results are reported in standard per mil notation, relative to SMOW (Standard Mean Ocean Water). The standard NBS#28 has a $\delta^{18}\text{O}$ value of 9.40/00 +/- 0.2 (12 analyses) for this study.

IV. MINERAL CHEMISTRY AND PETROGRAPHY

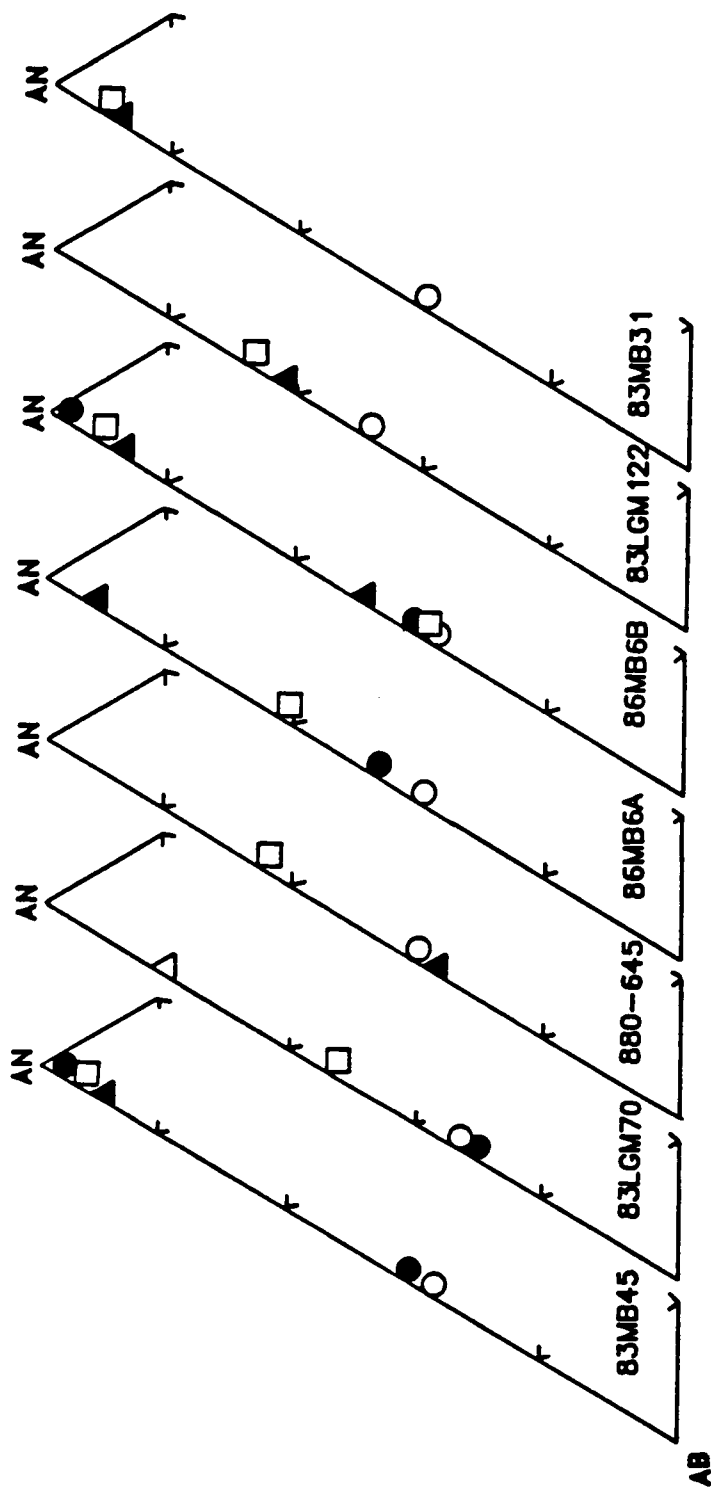
Three plagioclases occur in different combinations within the anorthosite: andesine (An₃₄₋₄₈), labradorite (An₅₁₋₆₅), and anorthite (An₈₂₋₉₈). Hornblende and biotite are the dominant mafic phases. Other phases include, chlorite, zoisite, muscovite, sericite, epidote, and kyanite (Table 1).

Several distinctive types of anorthosite and other plagioclase-rich rocks have been identified based on the textural relationships of the three plagioclases. Electron microprobe and petrographic analyses are summarized in Figure 2. The massive and foliated textures described by Hietanen (1963, 1969, 1984), Nord (1973), Juras (1974) and Goldberg (1983) are not unlike the massive and foliated textures described in this study. However, careful petrographic analysis has led to the identification of two textures not mentioned in the literature, sheared anorthosite and plagioclase-rich (+/- quartz) veins. For the purpose of intercomparison, a brief description of textures which have been previously described is given below.

Hietanen (1963) identified two varieties of anorthosite, massive and layered. In her study, massive anorthosite possessed two plagioclases, andesine or labradorite, with inclusions of bytownite and/or anorthite (1963). Layered anorthosite consisted of light colored (5-50 cm thick) layers

Figure 2: Electron microprobe and petrographic analyses.

This plot shows average plagioclase compositions of the different grain types occurring within several anorthosite samples. In all samples, megacrysts are andesine in composition. Inclusions are typically anorthite, but some samples do contain andesine and labradorite inclusions. Fine-grained aggregates range in composition from andesine to anorthite, and fine to medium grains with no inclusions are andesine or anorthite.



- MEGACRYST WITH ORIENTED INCLUSIONS
- ▲ INCLUSIONS IN MEGACRYSTS
- FINE-GRAINED AGGREGATES
- FINE- TO MED-GRAINED PLAG, NO INCLUSIONS

of andesine-bytownite rock and thin dark layers rich in biotite, muscovite, or hornblende (Hietanen, 1963, 1984). A fine-grained groundmass of bytownite-anorthite surrounding large andesine containing bytownite-anorthite inclusions occurred in the light-colored layers of the layered anorthosite.

Two massive varieties and one foliated variety of anorthosite were described by Nord (1973). The massive varieties are hornblende bearing and possess two or three plagioclases phases. Large (up to 5 cm) andesine or labradorite grains with bytownite-anorthite inclusions occur within an andesine and anorthite groundmass.

The foliated variety described by Nord is a two plagioclase anorthosite, containing andesine (An40-45) and bytownite-anorthite (An80-97) and found interlayered with pelitic schist. In this variety of anorthosite, layers of calcic plagioclase (0.25-1.0 mm) alternate with layers of andesine.

Juras described a coarse-grained, equigranular, massive anorthosite which consists of labradorite with optically continuous bytownite-anorthite inclusions. Foliated anorthosite consists of layers of "schistose micaceous or cataclastic anorthosite alternating with layers of anorthosite" (Juras, 1974).

Goldberg identified massive anorthosite as a coarse- to medium-grained rock containing lath-shaped andesine or

labradorite crystals, twinned by albite, pericline, Carlsbad laws occurring in a matrix of bytownite or anorthite. Foliated anorthosite possesses fine-grained calcic plagioclase that alternate with larger andesine or hornblende grains (Goldberg, 1983).

Massive Anorthosite

Massive anorthosite is the dominant variety of anorthosite, occurring throughout the anorthosite body. Its coarse-grained texture (plagioclase megacrysts up to 20 mm in length) is easily recognized in hand sample. Massive anorthosite typically possesses large, anhedral (2-20 mm) andesine (An_{34.6-48.0}) megacrysts; (Table 2) that are untwinned or twinned by Carlsbad, pericline, and albite twin laws. The megacrysts are often embayed by surrounding grains, as well as sericitized. Optically-continuous anorthite (An_{76.4-96.9}) inclusions (<0.5 mm maximum dimension) occur within the andesine megacrysts of all massive samples (Figure 3). Some samples also possess labradorite (An 50-65) inclusions and/or andesine (An₄₁₋₅₀) inclusions, but they are scarce. Andesine inclusions occurring within an andesine host as euhedral, bladed grains with high optical relief. Inclusions may be the same composition or slightly more calcic than the andesine host, but are rarely more sodic. A number of inclusion morphologies occur within the andesine megacrysts, including blade-like, bleb-like, and fine

Table 2: Petrography and Mineral Compositions of Massive Anorthosite

Sample			83MB 45	86MB 6B	90LGM 37A	83LGM 122	83MB 15	86MB 6A	84LGM 123	84LGM 121	880 645
Mega		An35-48	X	X	*	*	X	X	*	*	*
Inc w/in mega		An40-50			*	X			*		
		An50-80		X		X	X				
		An80-95	X	X		X	X	X	*	*	*
Large	> 2.0 mm	An35-45			X						
Medium	0.5-2.0 mm	An38-47	X		X						
Fine	0.13- 0.5 mm	An40-50							*	*	*
		An50-65						X			
		An65-80									
Grains along borders of mega	0.03- 0.13 mm	An50-65		X			X				
		An85-99				*	X			*	*
		An85-99									
Laminae		An85-99									

X = composition is known, * = composition is unknown

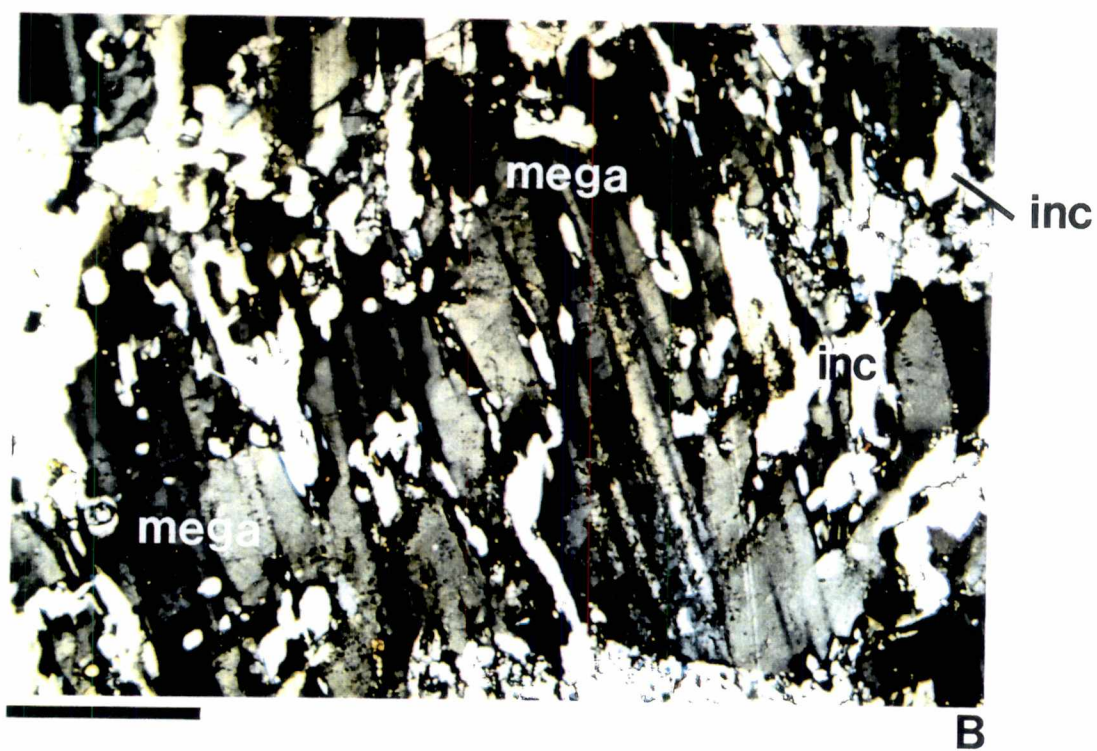
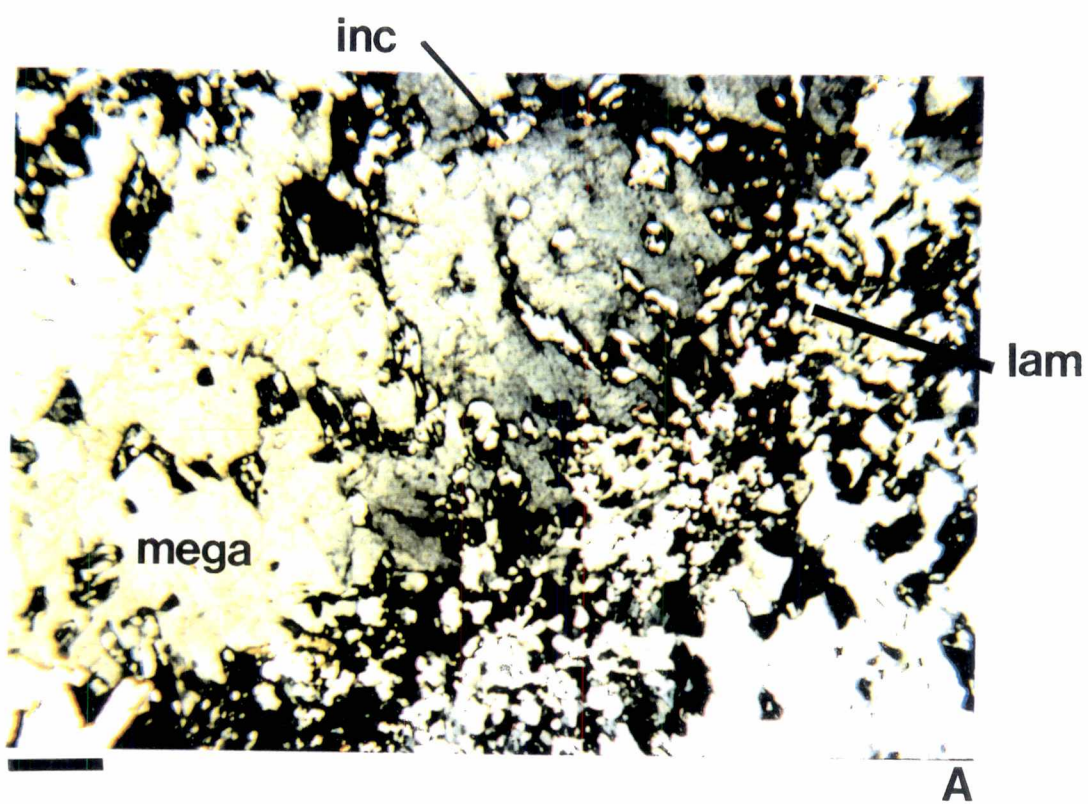
Table 2: (cont.)

Sample			83MB 31	83MB 18	90LGM 36	83LGM 124	90LGM 37B	90LGM 39	90MB 46	90LGM 49
Mega		An35-48	X	X	*	*	*	X	*	*
Inc w/in mega		An40-50			*	*	*	X		
		An50-80								
		An80-95	X	X					*	*
Large	>2.0 mm	An35-45								
Medium	0.5-2.0 mm	An38-47	X		*	*	*			
Fine	0.13-0.5 mm	An40-50			*	*	*	*		
		An50-65								
		An65-80								
Grains along borders of mega	0.03-0.13 mm	An50-65		*	X	*	*	X	*	*
		An85-99	X							
		An85-99	X	X	*	*	*			
Laminae										

X = composition is known, * = composition is unknown

Figure 3: Photomicrographs of massive anorthosite.

(A) The andesine megacrysts (mega) in this sample of massive anorthosite, sample 83MB45, range in composition from An38-42. Anorthite (An84-95) inclusions (inc) occur within the megacrysts. Granoblastic-polygonal grains occurring as laminae (lam) are also anorthite in composition (An90-98). Very fine, brittle fractures are visible in this sample. (B) An andesine megacryst with optically continuous anorthite inclusions (86MB6A). The scale of both photos is 0.5 mm.



recrystallized aggregates. Blade-like inclusions are subhedral (0.1-0.5 mm), are not located preferentially along twin planes, and are most often observed in untwinned megacrysts. Bleb-like inclusions are anhedral (0.1-0.5 mm) and often coalesce. Fine-grained aggregates (0.03-0.13 mm total dimension) of recrystallized inclusions having 120 degree grain boundary angles occur within some megacrysts. In some samples, granoblastic-polygonal megacrysts are bordered by fine grained (0.05-0.25 mm), granoblastic-polygonal labradorite and anorthite. Fine (0.1-0.2 mm) granoblastic-polygonal grains of anorthite occur as laminae (layers) (up to 3 mm) in most massive anorthosite samples, as well as in other anorthosite varieties. These laminae cross-cut some andesine megacrysts, but are scarce in massive samples as they tend to form a foliation. Medium (0.5-2.0 mm) twinned (albite and pericline) and untwinned andesine (An_{37.9-43.8}) grains occur in some massive samples. A few subhedral garnet grains were observed in massive anorthosite. In one sample, garnet was embayed by corroded hornblende and in another, garnet was rimmed by chlorite. Calcic amphibole with ferrian tschermakite substitution was observed in these samples. Both massive and feathery amphibole are dark green or brownish-green, usually possessing plagioclase and chlorite inclusions. Fine, brittle fractures (0.1 to 0.3 mm) are most visible on a cut face.

Massive samples are easily distinguished petrographically

from other varieties of anorthosite due to the dominance of megacrysts and few finer grains. Samples possessing numerous medium and fine grains are more difficult to distinguish and appear to grade into *sheared anorthosite*.

Sheared Anorthosite

Few massive samples have been extensively sheared, resulting in grain size reduction, but no change in plagioclase compositions. Anhedral andesine megacrysts with optically continuous inclusions occur in sheared samples, but they are scarce and are much finer grained (<2.0 mm) (Table 3, Figure 4). Because megacrysts with inclusions are the most distinctive feature of massive anorthosite it was necessary to define sheared anorthosite as a separate group. Fine laminae (up to 3 mm thick) consisting of recrystallized bytownite-anorthite grains (0.1-0.2 mm) occur in large numbers within sheared anorthosite. Fine-grained (up to 0.5 mm) andesine, labradorite, and anorthite also occur outside of laminae, and may be either untwinned or twinned (albite and pericline laws). Sheared samples possess chlorite, an alteration product of biotite, as well as garnet and calcic amphibole with ferrian tschermakite substitution.

Foliated Anorthosite

A foliated variety of BBA is composed of alternating layers (up to 30 mm thick) of medium to fine (0.03-1.0 mm)

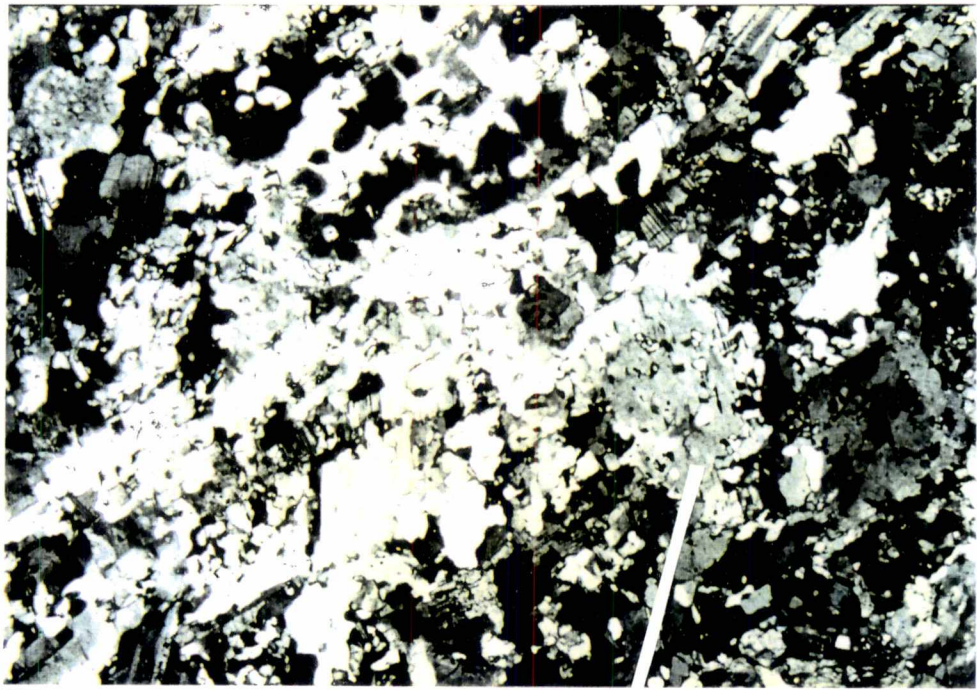
Table 3: Petrography and Mineral Compositions of Sheared Anorthosite

Sample			90LGM18A	90LGM18B	90LGM18C	90LGM18D
Mega		An35-48	*	X	X	X
Inc w/in mega		An40-50	*			
		An50-80		X		X
		An80-95			X	X
Large	>2.0 mm	An35-45				
Medium	0.5-2.0 mm	An38-47				
Fine	0.13-0.5 mm	An40-50	*	*		
		An50-65			X	
		An65-80			X	
Grains along borders of mega	0.03-0.13 mm	An50-65	*	X	*	X
		An85-99				X
Laminae		An85-99	*	*	*	X

X = composition is known, * = composition is unknown

Figure 4: Photomicrograph of sheared anorthosite.

Sheared anorthosite appears to have formed by grain-size reduction of massive anorthosite. A few andesine megacrysts (mega) with optically continuous inclusions remain and numerous fine andesine and anorthite grains are present. Labradorite also occurs in sheared anorthosite. This is a photomicrograph of sample 90LGM18E. Scale = 0.5 mm.



mega

anhedral andesine (An34-48) and anorthite (An82-92). Fine labradorite (An56) also occurs. Andesine (An38-40) megacrysts with anorthite (An87-93) inclusions occur within foliated anorthosite (Table 4). One kyanite inclusion was identified within an andesine megacryst in sample 83LGM70. This sample also possesses anhedral garnet with inclusions of biotite and/or andesine. Minor minerals are more abundant in foliated anorthosite than in massive and sheared anorthosite. Muscovite, biotite, chlorite, and hornblende elongation further define the foliation in the rock (Figure 5). Although the foliation is apparent in hand sample, without petrographic aid, this type of anorthosite is sometimes difficult to distinguish from sheared anorthosite. This variety of anorthosite occurs near the contact with surrounding metasediments, as well as in zones interfingering with the massive anorthosite.

Plagioclase-rich Rocks Not Included in the BBA

Other plagioclase-rich rocks are exposed within or near the BBA, but are not inferred to be part of the BBA. These rocks include plagioclase-rich schist and plagioclase (+/- quartz) veins.

Plagioclase-Rich Schist

Plag-rich schist occurs interlayered with and surrounding the BBA. The plagioclase grains in the schist are less

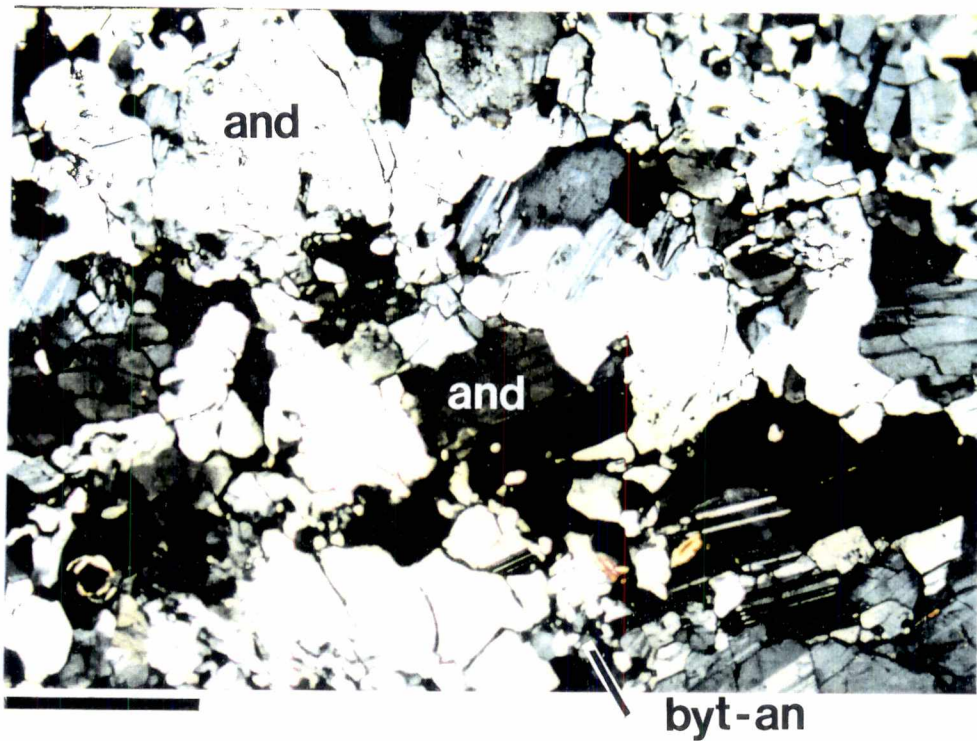
Table 4: Petrography and Mineral Compositions of Foliated Anorthosite

Sample			83LGM70	83LGM71	83LGM125
Mega		An35-48	X	*	
Inc w/in mega		An40-50		*	
		An50-80			
		An80-95	X		
Large	> 2.0 mm	An35-45			*
Medium	0.5-2.0 mm	An38-47	X	*	*
Fine	0.13-0.5 mm	An40-50		*	*
		An50-65	X		
		An65-80			
Grains along borders of mega	0.03-0.13 mm	An50-65	X		
		An85-99			
		An85-99	X	*	*
Laminae					

X = composition is known, * = composition is unknown

Figure 5: Photomicrographs of foliated anorthosite.

Top and bottom photomicrographs of foliated anorthosite are of samples 83LGM70 and 83LGM71, respectively. Foliation is defined by layers of different plagioclase compositions and mica and amphibole elongation. Scale = 0.5 mm. Abbreviations: and = andesine, byt-an = bytownite-anorthite, hbl = hornblende.



altered than in the anorthosite and are oligoclase in composition (An18-20) (Figure 6). They occur as medium, twinned (albite or pericline laws) or zoned grains. All three alumino silicate polymorphs (kyanite, andalusite, sillimanite) occur in this Al- and Mg-rich schist.

Plagioclase (+/-Quartz) Veins

The anorthosite and plagioclase-rich schist are discordantly crossed by plagioclase (>90%) or plagioclase and quartz veins. Each sample contains anhedral, twinned and untwinned plagioclase grains and a single plagioclase phase: andesine (An36-41) in plag-rich veins or oligoclase (An26-30) in plagioclase + quartz veins (Figure 7).

Cathodoluminescence

Mora and Ramseyer (1992) analyzed plagioclases from the BBA using cathodoluminescence (CL) petrography and found it useful because it permits the recognition of complex plagioclase intergrowths, compositional zonation, subgrain formation, and subtle brittle fractures that may be invisible in transmitted light. Plagioclases within the BBA luminesce differently allowing the rapid distinction of different phases. Calcic plagioclase has a bright yellow luminescence, whereas intermediate plagioclase luminesces a greenish color. Luminescence of all plagioclases indicates that all have a relative high-temperature origin, as authigenic and low

Figure 6: Photomicrograph of plagioclase-rich schist.

The plagioclase (pl) within sample 84LGM117 is oligoclase (An18-20) in composition. Biotite (bt) is also present. Scale = 0.5 mm.

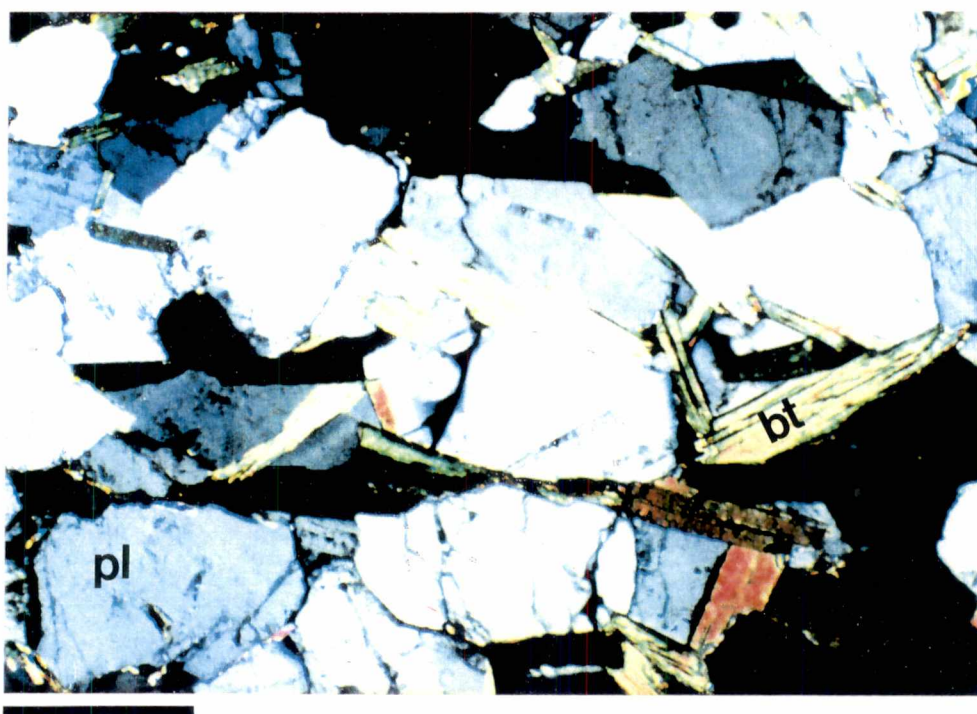
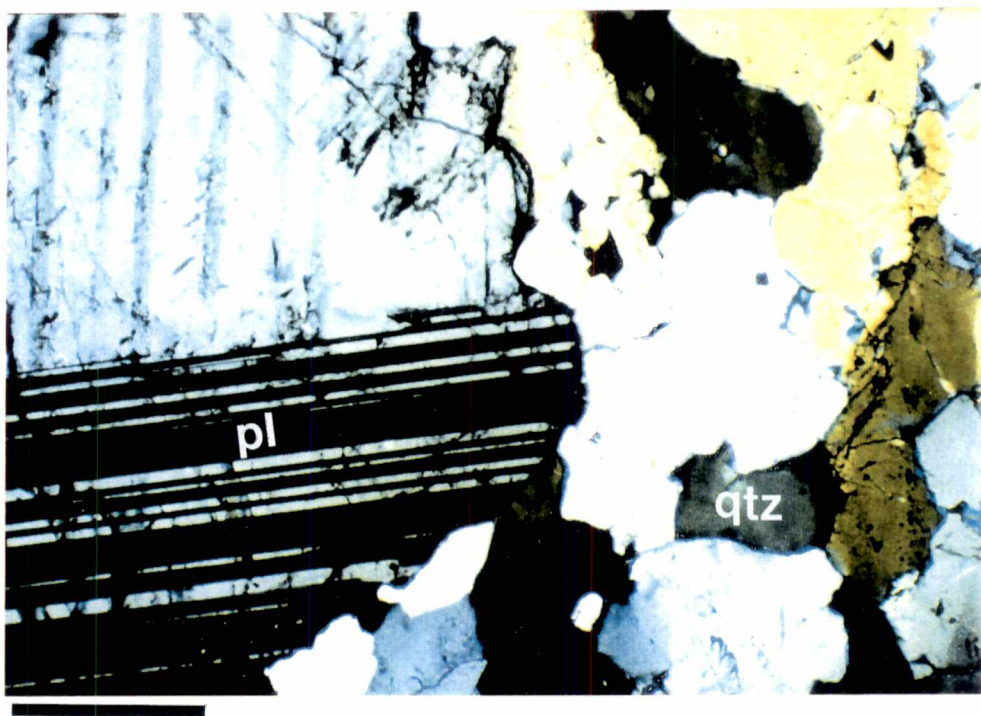


Figure 7: Photomicrograph of plagioclase (+/-quartz) vein.

The plagioclase (pl) within sample 83MB38 is oligoclase in composition. Quartz (qtz) is also present. Scale = 0.5 mm.



grade metamorphic plagioclases rarely luminesce (Kastner, 1971). Anorthite inclusions within andesine megacrysts have different CL peak positions and intensities than anorthite occurring in laminae. Based on evidence of dissolution and replacement, and grain dilatation and fragmentation occurring along laminae, they are inferred to be the path of retrograde fluid flow (Mora and Ramseyer, 1992).

V. ISOTOPIC COMPOSITIONS

Whole-plagioclase Analyses

The BBA possesses a broader range of $\delta^{18}\text{O}$ whole-plagioclase values than observed in unmetamorphosed Proterozoic; anorthosites. Whole-plagioclase and whole-rock analyses by Mora and Valley (1988a) and from this study are listed in Table 5. A histogram of $\delta^{18}\text{O}$ values is given in Figure 8, and includes analyses by Taylor (1969) not included in Table 5. The $\delta^{18}\text{O}$ (wp or wr) values for BBA range from -5.9 to 10.1 ‰ SMOW and include the lowest values reported for anorthosites. Other examples of isotopically-depleted anorthosites include portions of the Marcy anorthosite massif in the Adirondacks, New York (Morrison and Valley, 1988) and the Bitterroot anorthosite massif, Montana (Mora and Valley, 1988a). The ^{18}O -depleted values in the Marcy massif occur near the contact and range from 3.0 to 5.8 ‰. These depleted values are attributed to isotopic exchange with heated meteoric water when the anorthosite intruded at shallow levels prior to granulite facies metamorphism (Morrison and Valley, 1988). The Bitterroot anorthosite retains $\delta^{18}\text{O}(\text{SMOW}) = -2.9$ to 7.7 ‰, indicating isotopic exchange with channelized, heated meteoric-hydrothermal fluids (Mora and Valley, 1988a). Geochemically, the Bitterroot anorthosite (BIT) is similar to the BBA, and is thought to be genetically related (Goldberg, 1983). Geochemical similarities between the two anorthosites include less than 5% mafic phases, small transition elemental

Table 5: Oxygen Isotope Analyses of the Boehls Butte Anorthosite

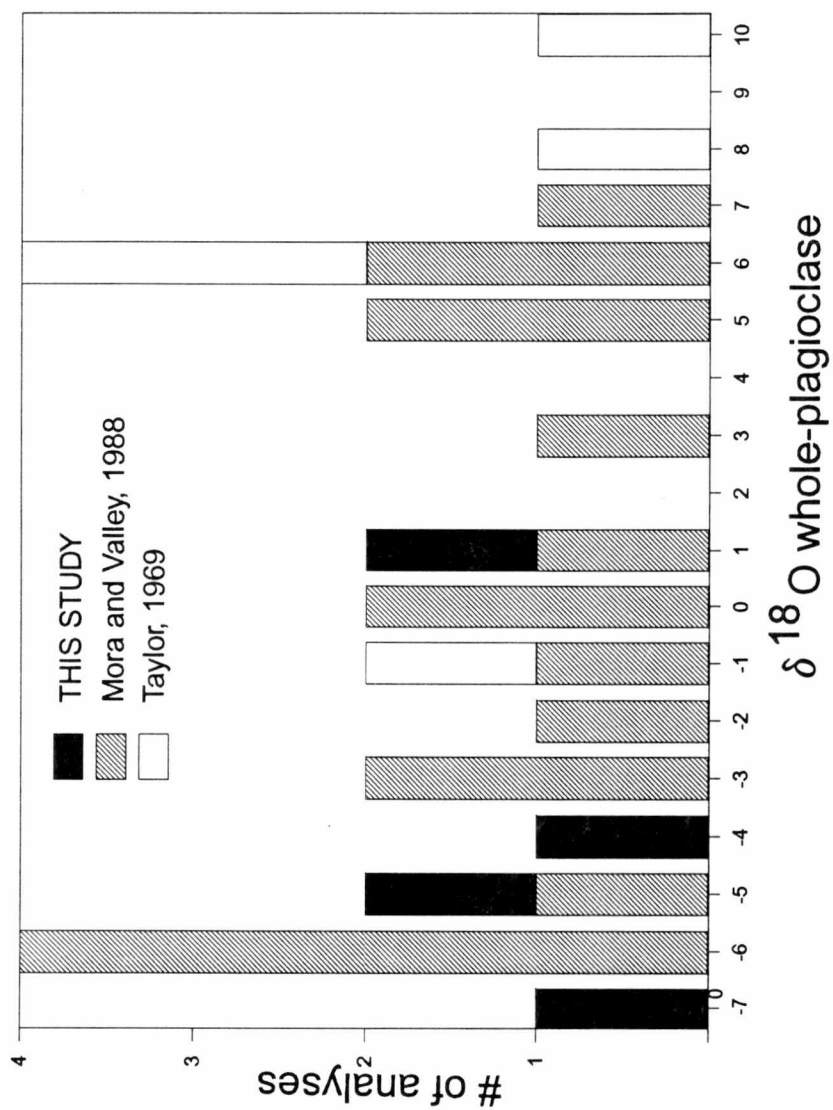
Sample	$\delta^{18}\text{O}(\text{wp})$	$\delta^{18}\text{O}(\text{Andesine})$ An30-50	$\delta^{18}\text{O}(\text{Anorthite})$ An80-100	$\Delta^{18}\text{O}(\text{An30-50}$ An80-100)
Massive				
83MB15	0.2	0.4	1.3	-0.9
90LGM39	-6.2	-5.3	-6.5	1.2
83LGM122	0.4	0.5	0.8	-0.3
86MB6A	5.7	6.1	5.5	0.6
86MB6B	na	6.3	na	na
90LGM37A	-2.8	-6.0	-7.2	1.3
83MB45	-4.0	-2.5	-4.1	1.6
83MB18	-0.5	-0.2	-0.2	0.3
83MB31	6.1	7.2	5.3	1.9
83MB16	-0.5	na	na	na
83MB64	1.6	na	na	na
83LGM56	-5.1	na	na	na
83LGM123	-2.8	na	na	na
83LGM124	-2.1	na	na	na
Sheared				
90LGM18B	na	-5.5	-6.0	0.6
90LGM18C	-5.8	-5.6	-5.7	0.2
90LGM18D	1.7	1.2	na	na
Foliated				
83LGM70	5.0	5.2	5.2	0.0
83LGM71	6.0	6.7	5.8	0.9
Other Plag-rich (+/- Quartz) Veins				
83MB33	-3.1	na	na	na
83LGM131	7.0*	na	na	na
83LGM127	7.5*	na	na	na

* whole-rock analyses

na - Not analyzed

Figure 8: Histogram of $\delta^{18}\text{O}$ (whole-plagioclase).

Histogram displaying the broad range of $\delta^{18}\text{O}$ whole-plagioclase/whole-rock values for BBA, including analyses not listed in Table 5 (Taylor, 1969; Mora and Valley, 1988a; this study).



values, small K/Rb ratios, large positive Eu anomalies, and small REE abundances (Goldberg, 1983). One major difference between the two anorthosites is the simpler mineralogy of the BIT anorthosite. It contains only a single plagioclase phase (An40-50) (Mora and Valley, 1988a).

Plagioclase Separates

In this study, plagioclase separates of An30-50 (andesine) and An80-100 (anorthite) were analyzed isotopically to aid in interpreting the origin of the BBA as well as its unique geologic history. An earlier study (Taylor, 1969) suggested possible isotopic disequilibrium between coexisting plagioclases based on analyses ($\delta^{18}\text{O} = 6.8$ and 8.4 ‰) of two plagioclases of apparently different, but unspecified compositions (clear, glassy plagioclase retained $\delta^{18}\text{O} = 8.4$ ‰). Analysis of plagioclase separates can be used to address previous hypotheses proposed by Hietanen (1963), Nord (1973), Juras (1974), Goldberg (1983), Mora and Ramseyer (1992), and help to understand the complex history experienced by the BBA.

Isotopic analyses of plagioclase separates and whole-plagioclase isotopic data from the same sample are consistent with whole-plagioclase compositions calculated based on the composition of separates and the mineralogical modes (Table 6). The measured values vary about ± 0.2 ‰ from calculated values, with the exception of samples 83MB45 and 86MB6A. The

Table 6: Consistency of Modes with Isotope Analyses

Sample	Normalized %		$\delta^{18}\text{O}$		$\delta^{18}\text{O}$ whole-plag	
	An30-50	An80-100	An30-50	An80-100	calculated	measured
83MB15	68	32	0.4	1.3	0.7	0.2
90LGM39	56	44	-5.3	-6.5	-5.9	-6.2
83LGM122	64	36	0.5	0.8	0.6	0.4
86MB6A	66	34	6.1	5.5	5.9	5.7
83MB45	69	31	-2.5	-4.1	-3.0	-4.0
83MB18	57	43	-0.2	-0.2	-0.2	-0.5
83MB31	78	22	7.2	5.3	6.8	6.1
83LGM70	76	24	5.2	5.2	5.2	5.0
83LGM71	82	12	6.7	5.8	6.2	6.0

precision can be attributed to the heterogeneity of the samples. Some samples possess a third plagioclase phase, labradorite, for which a clean separate could not be obtained. The contribution of this phase to the whole-plag $\delta^{18}\text{O}$ value is unknown. Furthermore, it was suggested using cathodoluminescence petrography that there are two generations of anorthite grains, those occurring as laminae and those occurring within andesine megacrysts (Mora and Ramseyer, 1992). Two different generations of anorthite grains may yield different isotopic compositions.

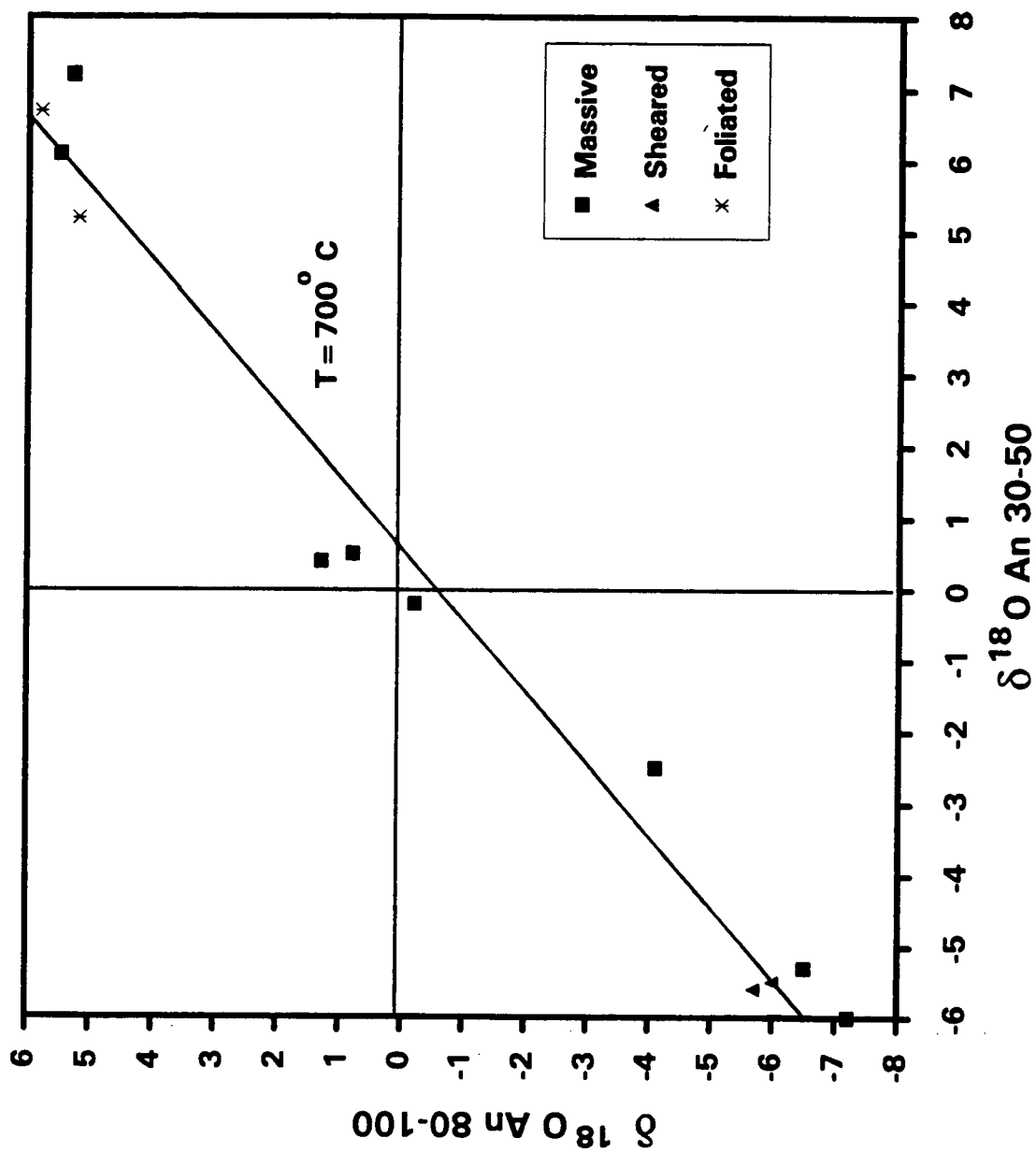
Plagioclase Fractionations

The oxygen isotope fractionation between An30-50 (andesine) and An80-100 (anorthite) may constrain the timing of fluid-rock interaction leading to isotopic depletions. It may also constrain the composition of the fluid with which the BBA exchanged. Based on the number of Si-O bonds in plagioclase, the Na-rich phase (An30-50) is predicted to be enriched in ^{18}O relative to the Ca-rich phase (An80-100). $\delta^{18}\text{O}(\text{andesine})$ ranges from -6.0 to 6.7 ‰, and $\delta^{18}\text{O}(\text{anorthite})$ from -7.2 to 5.8 ‰. The oxygen isotope fractionations between andesine and anorthite for these samples vary from $\Delta^{18}\text{O} = -0.9$ to $+1.9$ ‰ (Table 5). Variable oxygen isotopic fractionations between coexisting plagioclases in the BBA suggests widespread isotopic disequilibrium. Recalculation of the experimentally-determined value of $\Delta^{18}\text{O}$ ($1.02 \cdot 10^6 T^{-2}$; Clayton

et al., 1989) indicates that the expected equilibrium fractionation at 700°C (approximate peak M2 temperatures in the BB area; Grover et al., 1992) is 0.54‰. Only a few samples have this fractionation (Figure 9); many more samples have significantly higher or lower fractionation values of $\Delta^{18}\text{O}$. The oxygen isotopic fractionations in sheared and foliated BBA samples appear to be more consistent with an approach to peak metamorphic isotopic equilibrium than do massive BBA samples.

Figure 9: $\delta^{18}\text{O}(\text{An}_{30-50})$ versus $\delta^{18}\text{O}(\text{An}_{80-100})$.

Each symbol represents one sample. The line represents the equilibrium oxygen isotope fractionation at $700^\circ\text{C} = 0.54$ o/oo. This value was obtained using $\Delta^{18}\text{O}(\text{Ab-An}) = 1.02 \cdot 10^6 T^{-2}$, (Clayton et al., 1989), which was recalculated for andesine and anorthite.



VI. INTERPRETATION

Stable isotope analysis of plagioclase separates, petrographic evidence, and plagioclase compositional data may be used to determine isotopic equilibrium between plagioclase phases and to characterize fluid flow within the anorthosite. Oxygen isotope fractionations of andesine (An30-50) and anorthite (An80-100) may constrain the timing and composition of the meteoric-hydrothermal fluid with which the BBA has interacted since crystallization. It may also be used to address the different hypotheses proposed for the origin of the unique mineralogy and texture of the BBA.

Petrographic evidence suggest that andesine was present before the granoblastic-polygonal laminae of anorthite because andesine megacrysts are embayed and often cross-cut by laminae. In addition, CL petrography suggests that there are two generations of anorthite grains, those occurring as inclusions and those occurring as laminae (Mora and Ramseyer, 1992).

Isotopic Compositions and Textures

There appears to be some correlation between $\delta^{18}\text{O}(\text{wp})$ and $\Delta^{18}\text{O}(\text{andesine-anorthite})$ and the anorthosite type. A wide range of $\delta^{18}\text{O}(\text{wp})$ values occur in massive anorthosite ($\delta^{18}\text{O} = -6.2$ to 6.1 ‰). Less variable $\delta^{18}\text{O}$ values (-5.8 to 1.7 ‰) occur in sheared anorthosite, whereas foliated anorthosite

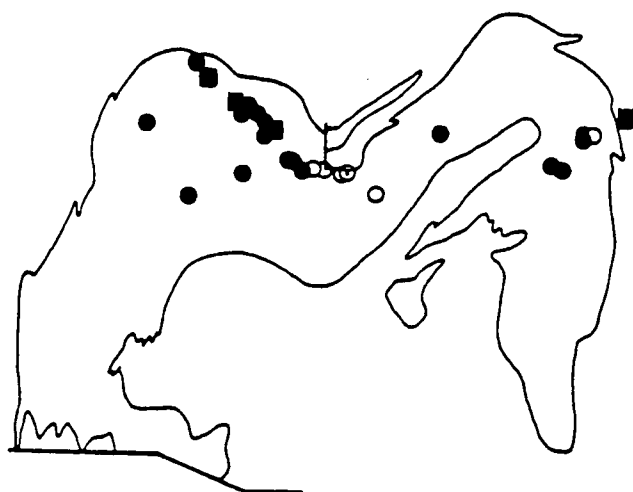
retains oxygen isotopic signatures consistent with most igneous anorthosites (5.0 to 6.0‰) (Table 5). Oxygen isotope fractionations between andesine (An30-50) and anorthite (An80-100) are variable, $\Delta^{18}\text{O} = -0.9$ to 1.9 ‰. More sheared anorthosite samples approach isotopic equilibrium at peak M2 temperatures (650-750°C) than do massive and foliated anorthosite samples. The spatial distribution of $\delta^{18}\text{O}(\text{wp})$ values and $\Delta^{18}\text{O}(\text{An30-50} - \text{An80-100})$ values within the BBA are shown in Figure 10. The lack of correlation between these values and location within the anorthosite suggest that fluid-flow through the anorthosite was largely channelized and limited to the anorthosite contact or other discrete portion of the anorthosite body.

Meteoric-Hydrothermal Alteration

^{18}O -depletions within the BBA indicate exchange with heated meteoric-hydrothermal fluid. Oxygen isotope fractionations of $\Delta^{18}\text{O}(\text{andesine-anorthite}) -0.9$ to 1.9 ‰ are greater than expected for feldspars equilibrated at peak metamorphic temperatures. Larger oxygen isotope fractionations record lower temperatures (250-350°C) and smaller oxygen isotope fractionations record higher temperatures. Clearly, these samples are not in isotopic equilibrium. In the majority of the samples analyzed (9 of 12), anorthite is more ^{18}O -depleted than andesine (Figure 11). This suggests that meteoric-hydrothermal fluid preferentially

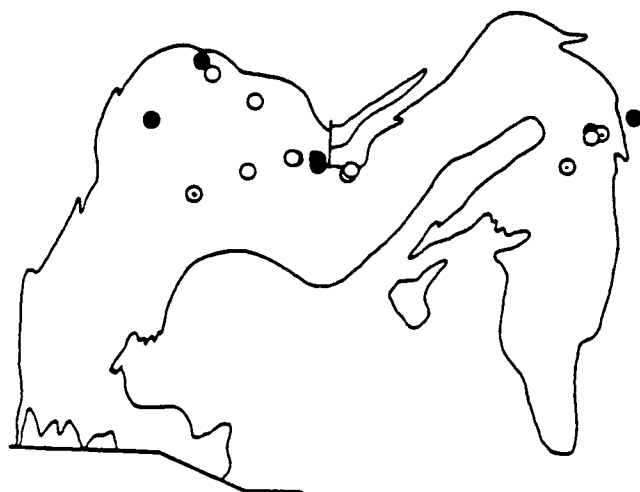
Figure 10: Sample locations.

(A) Map of the Boehls Butte anorthosite showing the sample locations of massive, sheared, and foliated anorthosite, as well as plagioclase (+/- quartz) veins. (B) Map indicating the $\delta^{18}\text{O}(\text{whole-plagioclase})$ values of BBA analyzed in this study. (C) Map indicating oxygen isotope fractionation values ($\Delta^{18}\text{OAn30-50} - \text{An80-100}$).



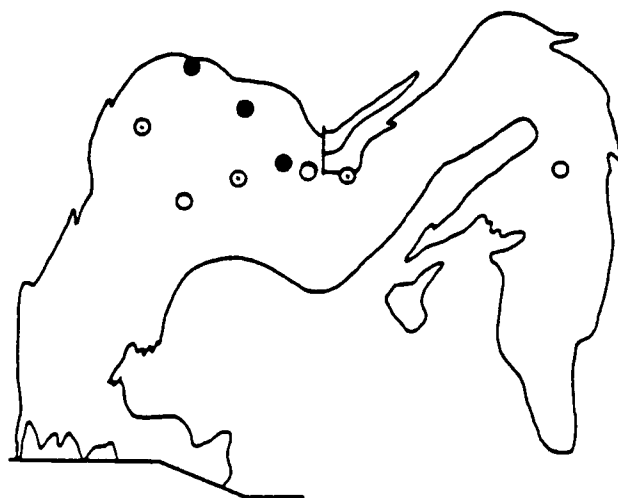
A. TEXTURE

- Massive
- Sheared
- Foliated
- Other



B. $\delta^{18}\text{O}$ (wp)

- >4
- $0-4$
- <0

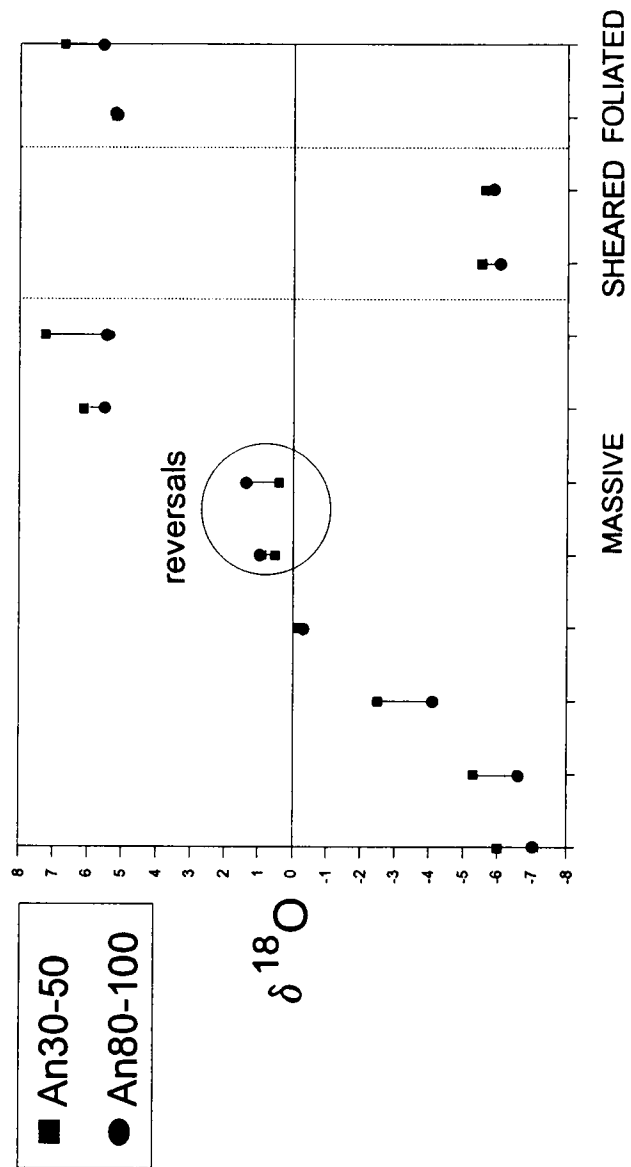


C. $\Delta^{18}\text{O}$ (An30-50 - An80-100)

- >0.9
- $0.2-0.9$
- <0.2

Figure 11: Oxygen isotope compositions of coexisting plagioclases.

Oxygen isotope compositions of andesine (An30-50) and anorthite (An80-100) in massive, sheared, and foliated anorthosite. The length of the line separating the two symbols represents the oxygen isotopic fractionation between the phases. Two samples, 83MB15 and 83LGM122, record isotopic "reversals", where andesine is ^{18}O -depleted relative to anorthite.



exchanged with calcic plagioclase. Therefore, fluid flow may have been focused along anorthite laminae. Evidence of dissolution, replacement, and grain fragmentation was identified within laminae using CL petrography, also suggesting that fluid flow was focused along laminae (Mora and Ramseyer, 1992).

Values of $\delta^{18}\text{O}(\text{wp})$ ranging from -5.9 to 10.1 ‰, with isotopic gradients up to 11.9 ‰ over approximately 250 m indicate that meteoric-hydrothermal fluid flow was dominantly channelized (Mora and Valley 1988a). The surrounding Belt Group metasediments of the Wallace Formation have also been affected by similar meteoric-hydrothermal fluid activity (Mora and Valley, 1988b, 1991). Large (+15.5‰) oxygen isotopic fractionations between quartz and calcite in some Wallace Formation samples suggest that the fluid event occurred after the peak of metamorphism (Mora and Valley, 1991).

Some of the most depleted samples retain apparent equilibrium (M2) $\Delta^{18}\text{O}$ values (Figure 9). Two samples which retain oxygen isotope fractionations consistent with equilibration at peak M2 temperatures are 86MB6A and 90LGM18C (Table 5). Sample 86MB6A (massive BBA) appears to retain the original igneous oxygen isotopic signature, suggesting that this sample did not interact with meteoric-hydrothermal fluid. Meteoric-hydrothermal fluid systems which are known to have developed around Eocene plutons of the Idaho batholith involved fluid-rock interaction with a very ^{18}O -depleted fluid

($\delta^{18}\text{O} = -16\text{‰}$) at $T = 150\text{--}400^\circ\text{C}$ (Criss and Taylor, 1983). Textural and cathodoluminescence observations suggest that fluid-rock interaction may have occurred at a higher temperature. Using the equilibrium fractionation curves for anorthite and H_2O (Matsuhisa et al., 1979), peak M2 temperatures ($650\text{--}750^\circ\text{C}$), and $\delta^{18}\text{O}$ values for anorthite, the composition of the fluid with which the BBA interacted was calculated for sample 90LGM18C (sheared BBA). The calculated fluid composition of $\delta^{18}\text{O} = -4.7\text{‰}$. This may indicate that fluid-flow within these samples occurred at or just after the peak of M2 regional metamorphism, while the rocks remained at elevated temperatures.

Constraints on the Origin of the BBA

Stable isotope analyses and mineral data can be used to address each of the previously proposed hypotheses.

Metasomatism

Hietanen's (1963) hypothesis of a metasomatic origin was related to the formation of the Idaho batholith, which she believed formed by the process of granitization. However, Goldberg showed that the BBA possessed very similar trace element and REE data to other anorthosites (1983), all of which were igneous in origin. Hietanen (1984) preferred a different hypothesis, favoring Nord's (1973) hypothesis, however, not ruling out local metasomatism. If calcic

plagioclase was created by migration of Al from shale into limestone and then altered by metasomatism to produce andesine, as proposed by Hietanen (1963) anorthite should be ^{18}O -enriched relative to andesine, as sedimentary rocks are typically ^{18}O -enriched. However, the results of this study indicate that anorthite is often ^{18}O -depleted relative to andesine.

Partial Melting Plus Metasomatism

Nord (1973) proposed that the anorthite in the anorthosite, including anorthite inclusions within the megacrysts were restites from partial melting of aluminous metasediments. If this were so, we would expect anorthite to be enriched in ^{18}O relative to andesine, as metasedimentary rocks are typically ^{18}O -enriched. This is not supported by the results of this study (Table 5). Furthermore, if labradorite was the first phase formed and later reaction with a hydrothermal fluid resulted in replacement of labradorite and anorthite to andesine, as proposed by Nord (1973), then $\delta^{18}\text{O}$ for andesine should be depleted relative to anorthite and less variable. Again, this is not supported by the isotopic results presented in this thesis. Petrographic evidence, particularly the presence of fluid inclusions within the andesine megacrysts, suggests superimposed hydrothermal alteration (Nord, 1973). CL petrography and oxygen isotope data do suggest reaction with a hydrothermal fluid.

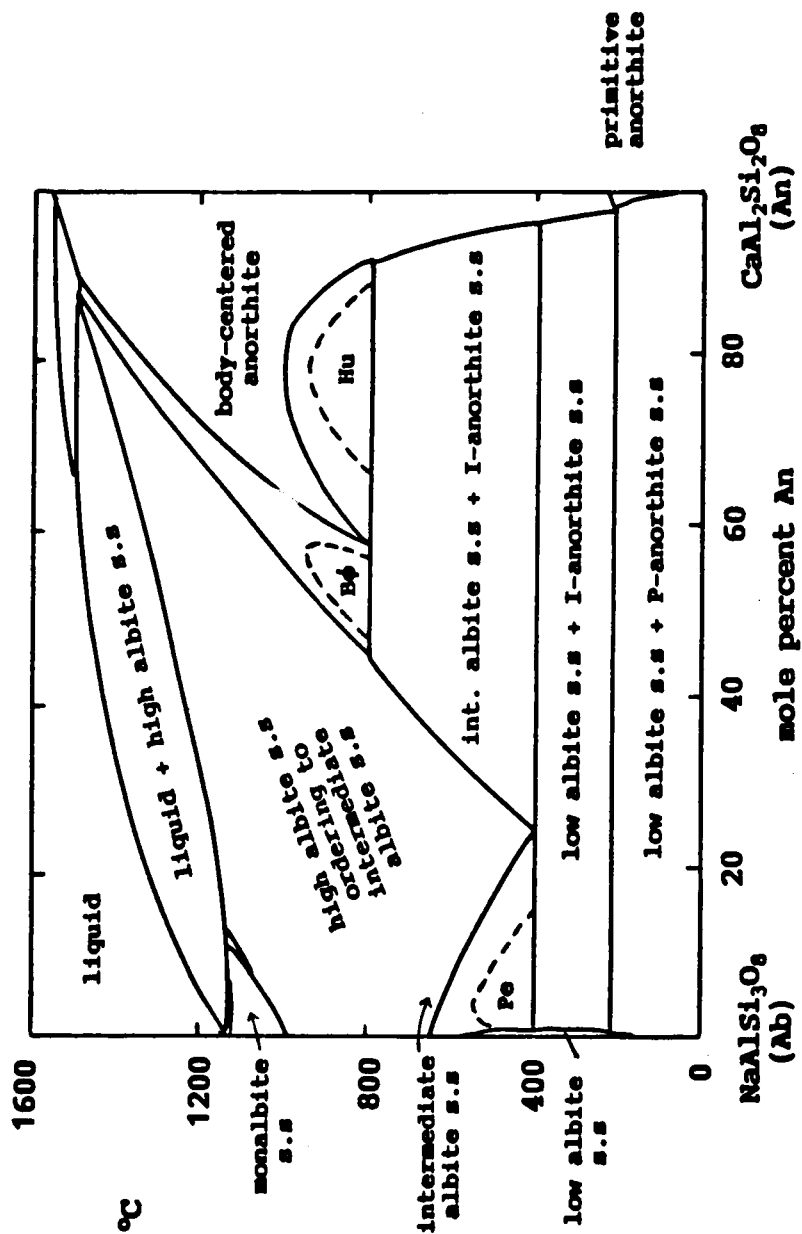
Exsolution and Shear Differentiation

Subsolidus exsolution of andesine and anorthite from labradorite, plus intense shearing producing alternating layers of andesine and anorthite, as proposed by Juras (1974), is problematic. Because andesine and anorthite are structurally incompatible, one might expect exsolution (Figure 12). However, the size of the inclusions within the BBA are many orders of magnitude coarser (mm scale) than others reported (micron scale). Peristerite intergrowths have the highest optical magnification (but still typically measured in μm), but these intergrowths occur in more sodic plagioclases. In order for exsolution to occur within plagioclase, Al and Si must be diffused, as well as Na and Ca; diffusion of Al and Si is virtually impossible at lower temperatures.

Shearing in the general area most likely occurred upon intrusion of the Idaho batholith and uplift of the BB Formation. Sheared anorthosite samples are ^{18}O -depleted suggesting substantial meteoric-hydrothermal alteration. Even though shearing often leads to coarsening, the shear strength difference between these plagioclases is small, and shear differentiation is unlikely. Finally, if coexisting plagioclases formed in this manner, andesine and anorthite should be found in isotopic equilibrium. It is in apparent equilibrium in only a few samples.

Figure 12: Hypothetical plagioclase phase diagram,

From Smith, J.V. (1974) Feldspar Minerals. I. Crystal structure and Physical Properties. Springer-Verlag: Heidelberg, 627p. Metastable curves which govern peristerite, Boggild, and Huttenlocher intergrowths as shown with a dashed line.



Igneous Intrusion with Complexities

Goldberg's (1983) hypothesis proposed igneous intrusion with mass transfer and assimilation at the contact. While it is most likely that the anorthosite crystallized from a melt of some sort, Figure 11 indicates that the entire anorthosite body was affected by post crystallization events, not just the contact rocks.

Alternate Hypothesis #1

None of the proposed hypotheses for the origin of the andesine megacrysts with anorthite inclusions is consistent with all of the petrographic and isotopic data obtained in this study. An alternate hypothesis for the origin of the unique mineralogy and texture of the BBA involves a relatively hot, hydrothermal fluid. Fluid flow occurring just after uplift of the BB Formation and while the rocks remained at elevated temperatures (500-600°C) may have leached labradorite of Na and Si leaving Ca and Al. This fluid may have been focused along the anorthite laminae. This might account for anorthite being ^{18}O -depleted relative to andesine. Samples do possess evidence of a reaction zone associated with the laminae, as CL petrography indicates that laminae are zoned (Mora Ramseyer, 1992). Andesine megacrysts are embayed by the laminae. Finally, anorthite inclusions are optically continuous and are in optical continuity with the megacryst which contain them. Leaching of Si and Na from the megacrysts

may have formed the anorthite inclusions. Plagioclase (sodic rich veins) oligoclase-quartz or andesine veins are found throughout the anorthosite body. These veins are not the typical composition of veins which emanate from granites, which are quartz and potassium feldspar in composition, they may thus be the product of large scale leaching of the anorthosite.

Leaching as an alternate hypothesis is also problematic. Because not all samples with two plagioclases are ^{18}O -depleted, alteration exclusively by meteoric-hydrothermal fluids is unlikely. Evidence for both low temperature and high temperature fluid events exist. The fluid process may be a high temperature process that continues at lower temperature, or a high temperature fluid that has been superimposed by meteoric-hydrothermal fluid. The origin of this mysterious fluid and the preferential leaching of Na and Si are problems which remain.

Alternate Hypothesis #2

Another hypothesis involves subsolidus exsolution (Juras, 1974), with some modifications. As previously discussed, this hypothesis is problematic because of the large scale exsolution seen in the BBA (scale of mm) which are not typical of intergrowths known to occur within plagioclase. Metamorphic coarsening may be a possible explanation for the size of the inclusions within the BBA. Because the

compositions of the inclusions and megacrysts do not span the compositions of the intergrowths known to occur within plagioclase, it is suggested that the position of the metastable curves representing the plagioclase intergrowths (Figure 12) may be best represented by the compositions defined in this study.

REFERENCES

REFERENCES

- Ashwal, L.D., and Seifert, K.E. (1980) Rare-earth element geochemistry of anorthosite and related rocks from the Adirondack, New York, and other massif-type complexes. *Geological Society of America Bulletin*, 91, 659-684.
- Carey, J.W., Rice, J.M., Grover, T.W. (1992) Petrology of aluminous schist in the Boehls Butte region of northern Idaho: geologic history and aluminum silicate phase relations. *American Journal of Science*, 292, 455-473.
- Clayton, R.N. and Mayeda, T.K. (1963) The use of bromine pentafluoride in the extraction of oxygen from oxides and silicates for isotopic analysis. *Geochim. Cosmochim. Acta*. 27, 43-52.
- Clayton, R.N., Goldsmith, J.R., Mayeda, T.K. (1989) Oxygen isotope fractionation in quartz, albite, anorthite and calcite. *Geochim. Cosmochim. Acta*. 53, 725-733.
- Criss, R.E. and Taylor, H.P. Jr. (1983) An $^{18}\text{O}/^{16}\text{O}$ and D/H study of tertiary hydrothermal systems of the southern half of the Idaho batholith. *Geological Society of America Bulletin*, 95, 640-663.
- Emslie, R.F. (1985) Proterozoic anorthosite massifs, In A.C. Tobi and J.L.R. Torne, ed., *The deep Proterozoic crust in the North Atlantic provinces*. Dordrecht, Netherlands 39-60.
- Goldberg, S.A. (1983) Geochemical constraints on the origin of Proterozoic anorthosites, western United States. Unpublished PhD. dissertation, University of Oregon, Eugene, Oregon, 199p.
- Grover, T.W., Rice, J.M., Carey, J.W. (1992) Petrology of aluminous schist in the Boehls Butte region of northern Idaho: phase equilibria and P-T evolution. *American Journal of Science*, 292, 474-507.
- Heath, S.A., and Fairbairn, H.W. (1969) $\text{Sr}^{87}/\text{Sr}^{86}$ ratios in anorthosites and some associated rocks. In Isachsen, Y.W., ed., *Origin of Anorthosites and Related Rocks*, N.Y. State Museum and Science Service Memoir 18, 99-110.
- Hietanen, A.H. (1963) Anorthosite and associated rocks in the Boehls Butte quadrangle and vicinity, Idaho. *United States Geological Survey Professional Paper* 344-B, 78p.

- Hietanen, A.H. (1969) Metamorphic environment of anorthosite in the Boehls Butte area, Idaho. In Isachsen, Y.W., ed., *Origin of Anorthosites and Related Rocks*, N.Y. State Museum and Science Service Memoir 18, 371-386.
- Hietanen, A.H. (1984) Geology along the northwest border zone of the Idaho batholith, northern Idaho. *United States Geological Survey Bulletin* 1608, 17p.
- Isachsen, Y.W. and Moxham, R.L. (1969) Chemical variation in plagioclase megacrysts from two vertical sections in the main Adirondack metaanorthosite massif. In Isachsen, Y.W., ed., *Origin of Anorthosite and Related Rocks*, N.Y. State Museum and Science Service Memoir 18, 255-265.
- Juras, D. (1974) The petrofabric analysis and plagioclase petrography of the Boehls Butte anorthosite. PhD. dissertation, University of Idaho, 132p.
- Kastner, M.A. (1971) Authigenic feldspars in carbonate rocks. *American Mineralogist*, 56, 1403-1442.
- Lang, H.M. and Rice, J.M. (1985a) Metamorphism of pelitic rocks in the Snow Peak area, northern Idaho: Sequence of events and regional implications. *Geological Society of America Bulletin* 96, 731-736.
- Lang, H.M. and Rice, J.M. (1985b) Geothermometry, geobarometry, and T-X (Fe-Mg) relations in metapelites, Snow Peak, northern Idaho. *Journal of Petrology*, 26, 889-924.
- Matsuhisa, Y., Goldsmith, J.R., and Clayton, R.N. (1979) Oxygen isotopic fractionation in the system quartz-albite-anorthite-water. *Geochim Cosmochim. Acta.*, 43, 1131-1140.
- Mora, C.I. and Valley, J.W. (1988a) Channelized meteoric-hydrothermal alteration of the Boehls Butte and Bitterroot anorthosites, northern Idaho and Montana. *Transactions of the American Geophysical Union* 69, 1489.
- Mora, C.I. and Valley, J.W. (1988b) Postmetamorphic fluid-rock interaction in Wallace Formation calc-silicates NW of the Idaho batholith: Stable isotopic evidence. *Geological Society of America Abstracts with Programs* 20, A45.
- Mora, C.I. and Valley, J.W. (1991) Prograde and retrograde fluid-rock interaction in calc-silicates northwest of the Idaho batholith: stable isotope evidence. *Contributions to Mineralogy and Petrology*, 108, 162-174.

- Mora, C.I. and Ramseyer, K. (1992) Cathodoluminescence of coexisting plagioclases, Boehls Butte anorthosite: CL activators and fluid flow paths. *American Mineralogist*, 77, 1258-1265.
- Morrison, J., and Valley, J.W. (1988) Contamination of the Marcy anorthosite massif, Adirondack mountains, NY: petrologic and isotopic evidence. *Contributions to Mineralogy and Petrology*, 98, 97-108.
- Morse, S.A. (1982) A Partisan review of Proterozoic anorthosites. *American Mineralogist*, 67, 1087-1100.
- Nord, G.L., Jr. (1973) The origin of the Boehls Butte anorthosite and related rocks, Shoshone County, Idaho. Unpublished PhD. dissertation, University of California, Berkeley, California, 159p.
- Papezik, V.S. (1965) Geochemistry of some Canadian anorthosites. *Geochim. Cosmochim. Acta*, 29, 673-709.
- Reid, R.R., Morrison, D.A., Greenwood, W.R. (1973) The Clearwater orogenic zone: a relict of Proterozoic orogeny in central and northern Idaho. In *Belt Symposium 1973*, Department of Geology, University of Idaho, Idaho Bureau of Mines and Geology, 10-56.
- Reynolds, R.C., Whitney, P.R., Isachsen, Y.W. (1969) K/Rb ratios in anorthositic and associated charnockitic rocks of the Adirondack, and their petrogenetic implications. In Isachsen, Y.W., ed., *Origin of Anorthosite and Related Rocks*, N.Y. State Museum and Science Memoir 18, 267-280.
- Simmons, E.C. and Hanson, G.N. (1978) Geochemistry and origin of massif-type anorthosite. *Contributions to Mineralogy and Petrology* 66, 119-135.
- Skipp, B. (1987) Basement thrust sheets in the Clearwater orogenic zone, central Idaho and western Montana: *Geology*, 15, 220-224.
- Smith, J.V. (1974) *Feldspar Minerals. I. Crystal structure and Physical Properties*. Springer-Verlag: Heidelberg, 627p.
- Smith, J.V. and Brown, W.L. (1988) *Feldspar Minerals, Volume 1, Crystal structures, physical, chemical, and microtextural properties*, Springer Verlag, New York, 828p.
- Taylor, H.P. Jr. (1969) Oxygen isotopic studies of anorthosites, with particular reference to the origin of

bodies in the Adirondack Mountain, New York. In Isachsen Y.W., ed., Origin of Anorthosites and Related Rocks, N.Y. State Museum and Science Service Memoir 18, 111-134.

Wiebe, R.A. (1980) Anorthositic magmas and the origin of Proterozoic anorthosite massifs. Nature, 286, 564-567.

APPENDICES

APPENDIX A
Massive Anorthosite
Plagioclase Analyses

PLAGIOCLASE ANALYSES
SAMPLE: 83MB31 MASSIVE ANORTHOISITE

NOTES:	MEGACRYSTS	INCLUSIONS		MEDIUM		FINE in laminae							
		w/in mega G1		w/in mega G2		(0.03-0.13)							
GRAIN SIZE (mm):	(2.5)	(4.5)											
# PTS. ANALYZED:	3												
POINTS:	max. G1-19	min. G2-36	14	17	34	max. G3-1	min. G2-23	max. G5-7	min. G6-8	G7-21	G8-22	G9-25	G10-27
WT %	SiO2	57.14	57.21	44.51	45.21	44.46	57.06	43.78	45.21	45.08	44.65	42.90	44.49
	Al2O3	26.60	26.20	34.85	34.34	35.02	26.57	35.63	34.21	34.33	34.82	35.80	34.79
	Fe2O3 *	0.07	0.05	<0.05	0.08	0.14	<0.05	0.06	0.07	<0.05	0.06	0.07	<0.05
	CaO	8.72	8.27	18.45	17.99	18.56	8.63	19.40	17.90	18.27	18.60	20.05	18.61
	BaO	0.09	<0.05	0.16	0.07	<0.05	<0.05	0.11	0.05	0.15	0.05	<0.05	<0.05
	Na2O	6.52	6.82	0.96	1.28	0.88	6.53	0.51	1.25	1.14	0.98	0.16	0.99
	K2O	0.10	0.11	<0.05	<0.05	<0.05	0.11	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	TOTAL	99.24	98.66	98.93	98.97	99.06	98.90	99.49	98.69	98.97	99.16	98.98	98.88
CATIONS BASED ON 8 OXYGENS													
	Si	2.580	2.595	2.077	2.105	2.071	2.580	2.037	2.110	2.101	2.079	2.011	2.076
	Al	1.416	1.401	1.917	1.885	1.923	1.422	1.954	1.882	1.887	1.911	1.976	1.915
	Fe	0.002	0.002	0.000	0.003	0.005	0.000	0.002	0.003	0.000	0.002	0.003	0.000
	Ca	0.422	0.402	0.923	0.898	0.926	0.418	0.967	0.895	0.913	0.928	1.006	0.931
	Ba	0.002	0.000	0.003	0.001	0.000	0.000	0.002	0.001	0.003	0.001	0.000	0.000
	Na	0.571	0.600	0.087	0.116	0.080	0.573	0.046	0.113	0.103	0.088	0.014	0.090
	K	0.006	0.006	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000
	TOTAL	4.999	5.006	5.007	5.008	5.005	4.999	5.008	5.004	5.007	5.009	5.010	5.012
PLAG END MEMBERS													
	Or	0.6	0.6	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
	Ab	57.0	59.5	8.6	11.4	8.0	57.5	4.6	11.2	10.1	8.7	1.4	8.8
	An	42.2	39.9	91.1	88.5	92.0	41.9	95.3	88.7	89.6	91.2	98.6	91.2

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 83MB31 (cont.)

NOTES:		FINE in laminae (0.03-0.13)									
GRAIN SIZE (mm):											
POINT:		G11-28	G12-29	G13-30	G14-31	G2-32	G18-37	G19-38	G20-39	G21-40	
WT %											
SiO2		42.60	42.59	43.95	43.05	43.58	43.27	43.97	43.29	44.20	
Al2O3		36.04	35.89	35.01	35.63	35.60	35.70	35.23	35.67	34.79	
Fe2O3		0.07	0.09	0.07	<0.05	<0.05	<0.05	0.08	0.09	0.07	
CaO		19.92	19.95	18.79	19.54	19.52	19.70	19.11	19.53	18.88	
Bao		<0.05	0.12	<0.05	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	
Na2O		0.12	0.12	0.70	0.33	0.40	0.46	0.72	0.35	0.85	
K2O		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	
TOTAL		98.75	98.76	98.52	98.60	99.10	99.13	99.11	98.93	98.79	
CATIONS BASED ON 8 OXYGENS											
Si		1.999	2.001	2.060	2.021	2.034	2.022	2.051	2.025	2.068	
Al		1.994	1.988	1.934	1.972	1.959	1.966	1.937	1.967	1.917	
Fe		0.002	0.003	0.003	0.000	0.000	0.000	0.003	0.003	0.003	
Ca		1.002	1.004	0.944	0.983	0.976	0.986	0.955	0.979	0.946	
Ba		0.000	0.002	0.000	0.001	0.000	0.000	0.000	0.000	0.000	
Na		0.011	0.011	0.063	0.030	0.036	0.042	0.065	0.031	0.077	
K		0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	
TOTAL		5.008	5.009	5.004	5.007	5.006	5.016	5.011	5.005	5.011	
PLAG END MEMBERS											
Or		0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	
Ab		1.1	1.1	6.3	3.0	3.6	4.1	6.4	3.1	7.5	
An		98.9	98.7	93.7	96.9	96.3	95.9	93.6	96.9	92.5	

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 83MB45 MASSIVE ANORTHOSITE

NOTES:		MEGACRYSTS		INCLUSIONS		MEDIUM		FINE	
GRAIN SIZE (mm):		(3.3)		(5.0)		(0.5)		(<0.3)	
# PTS. ANALYZED:	3	min.	max.	min.	max.	min.	max.		
POINT:	G1-2	G1-12	G2-24	G2-30	G2-30	G3-8	G3-14	G4-5	G6-11
WT %	SiO2	57.87	57.19	58.41	58.04	57.04	57.36	43.14	44.87
	Al2O3	26.26	26.76	25.93	26.49	26.70	26.79	35.96	34.93
	Fe2O3 *	0.06	<0.05	<0.05	0.06	<0.05	<0.05	<0.05	<0.05
	CaO	7.97	8.62	7.77	8.22	8.89	8.55	19.74	18.43
	BaO	<0.05	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	Na2O	7.13	6.47	7.09	6.74	6.46	6.43	0.32	0.96
	K2O	0.11	0.07	0.10	0.08	0.10	0.11	<0.05	<0.05
TOTAL		99.40	99.17	99.30	99.63	99.19	99.24	99.16	99.19
CATIONS BASED ON 8 OXYGENS									
	Si	2.604	2.581	2.626	2.603	2.576	2.584	2.014	2.085
	Al	1.393	1.424	1.374	1.400	1.422	1.423	1.980	0.913
	Fe	0.002	0.000	0.000	0.002	0.000	0.000	0.000	0.000
	Ca	0.384	0.417	0.374	0.395	0.430	0.413	0.988	0.917
	Ba	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
	Na	0.622	0.566	0.618	0.586	0.071	0.562	0.029	0.086
	K	0.006	0.004	0.006	0.005	0.000	0.006	0.000	0.000
TOTAL		5.011	4.993	4.998	4.991	5.000	4.988	5.011	5.001
PLAG END MEMBERS									
	Or	0.6	0.4	0.6	0.5	0.6	0.6	0.0	0.0
	Ab	61.5	57.3	61.9	59.4	56.5	57.3	2.9	8.6
	An	37.9	42.2	37.5	40.1	42.9	42.1	97.1	91.4
									96.0

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 83MB45 (cont.)

NOTES: FINE

GRAIN SIZE (mm): (<0.3)

POINT:		G7-12	G8-13	G9-15	G10-16	G11-17	G12-19	G13-20	G14-23	G15-26	G16-27	max. G17-28	G18-31	G19-33
WT %	SiO2	43.42	43.53	44.21	45.05	45.43	43.71	43.90	43.51	44.56	43.42	43.18	44.13	44.10
	Al2O3	35.92	35.96	35.40	34.88	34.70	35.68	35.62	36.01	34.97	35.65	35.94	35.24	35.34
	Fe2O3 *	<0.05	0.05	0.05	0.08	<0.05	<0.05	<0.05	0.06	0.05	0.05	<0.05	<0.05	0.10
	CaO	19.68	19.68	18.88	18.41	18.36	19.44	19.47	19.61	18.53	19.47	19.92	18.98	18.92
	BaO	0.09	0.13	0.29	<0.05	0.05	0.07	<0.05	<0.05	0.08	<0.05	<0.05	<0.05	<0.05
	Na2O	0.33	0.34	0.75	1.11	1.14	0.45	0.58	0.32	0.94	0.39	0.29	0.70	0.71
	K2O	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	TOTAL	99.44	99.69	99.58	99.53	99.68	99.35	99.57	99.51	99.13	98.98	99.33	99.05	99.17
CATIONS BASED ON 8 OXYGENS														
	Si	2.022	2.023	2.055	2.087	2.101	2.035	2.039	2.023	2.075	2.029	2.014	2.057	2.054
	Al	1.972	1.970	1.939	1.905	1.892	1.959	1.951	1.974	1.920	1.964	1.976	1.937	1.940
	Fe	0.000	0.002	0.002	0.003	0.000	0.000	0.000	0.002	0.002	0.002	0.000	0.000	0.004
	Ca	0.982	0.980	0.940	0.914	0.910	0.970	0.969	0.977	0.924	0.975	0.995	0.948	0.944
	Ba	0.002	0.002	0.005	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000
	Na	0.030	0.031	0.068	0.100	0.102	0.041	0.052	0.029	0.085	0.035	0.026	0.063	0.064
	K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	TOTAL	5.008	5.008	5.009	5.009	5.005	5.006	5.011	5.005	5.007	5.005	5.011	5.005	5.006
PLAG END MEMBERS														
	Or	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ab	3.0	3.1	6.7	9.9	10.1	4.0	5.1	2.9	8.4	3.5	2.5	6.2	6.3
	An	96.8	96.7	92.8	90.1	89.9	95.8	94.9	97.1	91.5	96.5	97.5	93.8	93.7

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 90LGM37A MASSIVE ANORTHOSITE

NOTES:	LARGE w/out inc		MEDIUM zoned rim (0.7-1.0)		core		twinned		INCLUSIONS W/IN HORNBLEDE						
GRAIN SIZE (mm):	(2.3)														
# PTS. ANALYZED:	10		2		3		4								
POINT:	max. G1-3	min. G1-6	max. G1-16	min. G1-17	max. G3-19	min. G2-18	max. G3-19	min. G2-18	max. G3-19	min. G2-18	max. G3-19	min. G2-18	max. G3-19	min. G2-18	max. G3-19
WT %															
SiO2	57.09	58.77	56.39	57.83	55.57	57.62	56.83	57.75	57.07	56.46	56.46	57.07	56.46	56.46	56.46
Al2O3	27.05	25.99	27.47	26.37	27.77	26.47	26.63	26.46	26.82	27.20	26.82	26.82	27.20	27.20	27.20
Fe2O3 *	0.05	<0.05	0.14	<0.05	0.06	0.06	0.13	0.15	0.22	0.21	0.22	0.22	0.21	0.21	0.21
CaO	8.80	7.72	9.34	8.01	9.61	8.14	8.72	8.34	8.65	9.09	8.65	8.65	9.09	9.09	9.09
SrO	<0.05	0.05	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	0.05	<0.05	<0.05	<0.05
BaO	0.07	<0.05	0.07	<0.05	0.10	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	0.06	<0.05	<0.05	<0.05
Na2O	6.68	7.24	6.32	7.08	6.12	7.01	6.60	7.03	6.80	6.52	6.80	6.80	6.52	6.52	6.52
K2O	0.06	0.06	<0.05	0.08	<0.05	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	0.05	<0.05	<0.05	<0.05
TOTAL	99.80	99.83	99.73	99.37	99.28	99.30	98.91	99.79	99.72	99.48	99.72	99.72	99.48	99.48	99.48

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CATIONS BASED ON 8 OXYGENS													
Si	2.565	2.628	2.539	2.602	2.517	2.595	2.574	2.592	2.568	2.547			
Al	1.433	1.370	1.458	1.399	1.483	1.405	1.422	1.400	1.423	1.447			
Fe	0.002	0.000	0.005	0.000	0.002	0.002	0.004	0.005	0.007	0.007			
Ca	0.424	0.370	0.451	0.386	0.466	0.393	0.423	0.401	0.417	0.439			
Sr	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000			
Ba	0.001	0.000	0.001	0.000	0.002	0.000	0.000	0.000	0.001	0.000			
Na	0.582	0.628	0.552	0.617	0.537	0.612	0.579	0.612	0.593	0.570			
K	0.003	0.004	0.000	0.005	0.000	0.000	0.000	0.003	0.000	0.000			
TOTAL	5.010	5.001	5.006	5.009	5.008	5.007	5.002	5.013	5.010	5.010			
PLAG END MEMBERS													
Or	0.3	0.4	0.0	0.5	0.0	0.0	0.0	0.3	0.0	0.0			
Ab	57.6	62.7	55.0	61.2	53.4	60.9	57.8	60.2	58.6	56.5			
An	42.0	36.9	44.9	38.3	46.3	39.1	42.2	39.5	41.2	43.5			

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 83MB15 MASSIVE ANORTHO SITE

NOTES:	MEGACRYSTS				INCLUSIONS w/in mega G1 bleb-like				INCLUSIONS w/in mega G2						
GRAIN SIZE (mm):	(5.0)	(3.7)													
# PTS. ANALYZED:	4	min. G1-2	max. G1-6	max. G2-28	min. G2-29	max. 3	5	min. 7	9	21	22	23	24	max. 25	
POINTS:															
WT %	SiO2	58.63	56.71	56.80	58.25	45.55	54.69	55.79	46.52	53.15	47.09	54.72	46.12	45.09	
	Al2O3	25.55	26.88	26.65	26.00	34.42	28.35	27.64	34.14	29.56	33.37	28.47	34.07	34.77	
	Fe2O3 *	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.18	<0.05	<0.05	0.05	0.09	<0.05	<0.05	
	CaO	7.30	8.85	8.56	7.73	17.39	10.72	9.79	17.24	11.10	16.34	10.65	17.25	18.28	
	BaO	0.05	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	0.09	0.29	<0.05	0.13	0.13	0.14	
	Na2O	7.08	6.43	6.66	7.09	1.33	5.38	5.96	1.78	4.78	2.09	5.55	1.59	1.18	
	K2O	0.13	0.09	0.07	0.12	<0.05	0.05	0.06	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	
TOTAL		98.74	98.96	98.74	99.19	98.74	99.19	99.42	99.77	99.88	98.94	99.66	99.16	99.46	

CATIONS BASED ON 8 O²⁻ IONS

Si	2.647	2.567	2.576	2.622	2.120	2.482	2.522	2.143	2.412	2.180	2.477	2.138	2.092
Al	1.360	1.434	1.425	1.380	1.888	1.517	1.473	1.854	1.582	1.821	1.519	1.862	1.901
Fe	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.002	0.003	0.000	0.000
Ca	0.353	0.429	0.416	0.373	0.867	0.521	0.474	0.851	0.588	0.811	0.517	0.857	0.908
Ba	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.002	0.005	0.000	0.002	0.002	0.003
Na	0.619	0.564	0.586	0.619	0.120	0.474	0.523	0.159	0.420	0.188	0.188	0.143	0.106
K	0.007	0.005	0.004	0.007	0.000	0.003	0.003	0.000	0.000	0.000	0.003	0.000	0.000
TOTAL	4.987	4.999	5.007	5.001	4.996	4.997	5.001	5.009	5.007	5.002	5.008	5.002	5.010

PLAG END MEMBERS

Or	0.7	0.5	0.4	0.7	0.0	0.3	0.3	0.0	0.0	0.0	0.3	0.0	0.0
Ab	63.2	56.5	58.3	62.0	12.2	47.5	52.3	15.7	41.5	18.8	48.4	14.3	10.4
An	36.0	43.0	41.3	37.3	87.7	52.2	47.4	84.1	58.0	81.2	51.2	85.5	89.3

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 83MB15 (cont.)

NOTES:	INCLUSIONS		FINE adjacent to mega (0.03-0.13)									
	w/in mega G2											
GRAIN SIZE (mm):												
POINT:	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
	26	27	31	12	13	14	15	16	16	16	16	16
WT %												
SiO2	55.09	45.24	53.35	45.06	47.96	47.55	48.46	50.19				
Al2O3	27.97	34.57	28.62	34.56	33.00	33.16	32.45	31.48				
Fe2O3 *	0.05	<0.05	0.11	<0.05	0.06	0.13	0.05	<0.05				
CaO	10.01	17.83	11.06	17.70	16.00	16.13	15.31	14.09				
BaO	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05				
Na2O	5.96	1.39	5.28	1.27	2.27	2.23	2.78	3.49				
K2O	0.06	<0.05	0.08	<0.05	<0.05	<0.05	<0.05	0.05				
TOTAL	99.41	99.03	98.50	98.59	99.29	99.20	99.05	99.35				
CATIONS BASED ON 8 OXYGENS												
Si	2.504	2.103	2.447	2.103	2.209	2.194	2.235	2.300				
Al	1.499	1.895	1.547	1.901	1.792	1.804	1.764	1.701				
Fe	0.002	0.000	0.004	0.000	0.002	0.004	0.002	0.000				
Ca	0.488	0.888	0.543	0.885	0.790	0.798	0.757	0.692				
Ba	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001				
Na	0.504	0.125	0.469	0.115	0.202	0.200	0.249	0.310				
K	0.005	0.000	0.005	0.000	0.000	0.000	0.000	0.003				
TOTAL	5.002	5.011	5.015	5.004	4.995	5.000	5.007	5.007				
PLAG END MEMBERS												
Or	0.5	0.0	0.5	0.0	0.0	0.0	0.1	0.3				
Ab	50.6	12.3	46.1	11.5	20.4	20.0	24.8	30.8				
An	48.9	87.7	53.4	88.5	79.6	80.0	75.2	68.8				

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 880-645 MASSIVE ANORTHOSSITE

NOTES:	MEGACRYST	MEDIUM
GRAIN SIZE (mm):	(2.5)	(0.5)
# PTS. ANALYZED:	3	
POINT:	min. max.	
	G1-2 G1-3	9
WT %		
SiO ₂	58.30	56.93
Al ₂ O ₃	26.09	26.69
Fe ₂ O ₃ *	0.05	<0.05
CaO	8.17	9.02
BaO	<0.05	0.09
Na ₂ O	6.96	6.28
K ₂ O	0.18	0.18
TOTAL	99.75	99.47
		99.20
CATIONS BASED ON 8 OXYGENS		
Si	2.614	2.566
Al	1.379	1.433
Fe	0.002	0.000
Ca	0.393	0.436
Ba	0.000	0.002
Na	0.605	0.549
K	0.010	0.010
TOTAL	5.003	4.996
		4.998
PLAG END MEMBERS		
Or	1.0	1.1
Ab	60.0	55.1
An	39.0	43.7
		43.5

* Total Fe calculated as Fe₂O₃.

PLAGIOCLASE ANALYSES
SAMPLE: 86MB68 MASSIVE ANORTHOSSITE

NOTES:	MEGACRYSTS twinned		(3.7)		(2.0)		(4.5)		INCLUSIONS w/in mega G1 bleb-like		INCLUSIONS w/in mega G2 aggregates	
	max. G1-30	min. G1-27	3 max. G2-16	min. G2-18	3 max. G3-24	min. G3-25	3 min. G4-3	max. G4-4	29	31	32	13
GRAIN SIZE (mm):	(10)											
# PTS. ANALYZED:	3											
POINT:												
WT %												
SiO2	57.21	58.64	57.54	59.50	56.17	58.27	57.63	57.15	45.46	44.39	44.42	51.38
Al2O3	26.89	26.06	26.84	25.28	27.52	26.37	26.44	26.68	34.87	35.10	34.95	30.25
Fe2O3 *	<0.05	<0.05	0.07	0.05	0.09	0.10	0.11	0.22	0.07	0.06	0.05	<0.05
CaO	8.91	7.93	8.83	7.17	9.59	8.21	8.50	8.65	18.27	18.84	19.02	13.01
BaO	<0.05	<0.05	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.22	<0.05	0.06
Na2O	6.27	7.03	6.65	7.44	6.06	6.92	6.83	6.67	1.15	0.85	0.87	4.05
K2O	<0.05	0.08	0.06	0.09	0.06	0.06	0.07	0.07	<0.05	<0.05	<0.05	<0.05
TOTAL	99.28	99.74	100.06	99.53	99.49	99.93	99.58	99.44	99.82	99.46	99.31	98.65

CATIONS BASED ON 8 OXYGENS

Si	2.577	2.625	2.577	2.663	2.535	2.607	2.591	2.576	2.098	2.064	2.067	2.358
Al	1.428	1.375	1.417	1.334	1.464	1.391	1.402	1.417	1.897	1.924	1.917	1.640
Fe	0.000	0.000	0.002	0.002	0.003	0.003	0.004	0.007	0.002	0.002	0.002	0.000
Ca	0.430	0.380	0.424	0.344	0.464	0.394	0.419	0.418	0.903	0.939	0.948	0.641
Ba	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.001
Na	0.548	0.610	0.578	0.646	0.530	0.600	0.596	0.583	0.103	0.077	0.078	0.361
K	0.000	0.005	0.003	0.005	0.003	0.003	0.004	0.004	0.000	0.000	0.000	0.000
TOTAL	4.983	4.995	5.002	4.994	4.999	4.998	5.016	5.005	5.003	5.010	5.012	5.001

PLAG END MEMBERS

Or	0.0	0.5	0.3	0.5	0.3	0.3	0.4	0.4	0.0	0.0	0.0	0.0
Ab	56.0	61.3	57.5	64.9	53.2	60.2	58.5	58.0	10.2	7.5	7.6	36.0
An	44.0	38.2	42.2	34.6	46.5	39.5	41.1	41.6	89.8	92.1	92.4	63.9

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 86MB6B (cont.)

NOTES:		INCLUSIONS w/in mega g2 aggregates		FINE bordering mega (<0.3)							
GRAIN SIZE (mm):		15	34	36	38	39	40	G5-20	G6-21	G7-22	G8-26
POINT:											
WT %	SiO2	47.08	45.45	44.98	44.47	46.07	44.09	43.00	44.38	44.02	45.41
	Al2O3	33.35	34.64	35.07	35.29	34.37	35.21	36.18	35.30	35.27	33.75
	Fe2O3 *	<0.05	0.07	<0.05	0.05	<0.05	0.06	<0.05	0.05	0.08	0.57
	CaO	16.80	18.26	18.15	18.89	17.94	19.06	19.61	18.92	19.03	17.89
	BaO	0.11	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	Na2O	2.03	1.15	0.97	0.79	1.34	0.74	0.27	0.69	0.71	1.40
	K2O	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
TOTAL		99.37	99.57	99.17	99.49	99.72	99.16	99.06	99.34	99.11	99.02
CATIONS BASED ON 8 OXYGENS											
	Si	2.175	2.103	2.088	2.063	2.125	2.055	2.009	2.062	2.053	2.116
	Al	1.817	1.889	1.919	1.930	1.869	1.935	1.993	1.934	1.939	1.854
	Fe	0.000	0.002	0.000	0.002	0.000	0.002	0.000	0.002	0.003	0.020
	Ca	0.832	0.905	0.903	0.939	0.887	0.952	0.981	0.942	0.951	0.893
	Ba	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Na	0.182	0.103	0.087	0.071	0.120	0.067	0.024	0.062	0.065	0.126
	K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL		5.008	5.002	4.997	5.005	5.001	5.011	5.007	5.002	5.011	5.009
PLAG END MEMBERS											
	Or	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	Ab	17.9	10.2	8.8	7.0	11.9	6.6	2.4	6.2	6.4	12.4
	An	81.9	89.8	91.2	93.0	88.1	93.4	97.6	93.8	93.6	87.6

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 83LGM122 MASSIVE ANORTHOSSITE

NOTES:	MEGACRYSTS							INCLUSIONS w/in mega G1						
POINT:	min. G1-7	max. G1-34	min. G2-14	max. G2-15	G4-8a	max. G5-11a	min. G5-12a	8	9	10	max. 32	min. 33	35	
WT %														
SiO2	58.00	56.89	56.09	56.17	57.91	56.70	56.23	51.15	48.11	50.68	43.91	51.31	54.37	
Al2O3	26.36	26.91	26.85	27.34	26.26	27.14	26.96	30.66	32.39	30.56	35.56	30.80	28.48	
Fe2O3 *	0.05	<0.05	0.07	0.05	<0.05	0.07	<0.05	0.05	0.07	0.05	<0.05	0.06	0.13	
CaO	8.24	9.03	9.05	9.44	8.15	9.29	9.21	13.47	15.54	13.55	19.05	13.37	10.77	
BaO	0.06	0.09	<0.05	<0.05	na	na	na	0.18	0.12	0.11	0.20	<0.05	0.04	
Na2O	6.90	6.31	6.39	6.15	6.81	6.14	6.26	3.94	2.64	4.02	0.63	3.88	5.54	
K2O	0.08	0.06	0.07	0.07	0.07	0.09	0.08	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	
TOTAL	99.69	99.29	98.52	99.22	99.20	99.43	98.74	99.45	98.87	98.97	99.35	99.42	99.33	
CATIONS BASED ON 8 OXYGENS														
Si	2.603	2.568	2.554	2.541	2.608	2.556	2.554	2.340	2.227	2.331	2.045	2.545	2.469	
Al	1.395	1.432	1.441	1.458	1.394	1.442	1.444	1.653	1.768	1.657	1.952	1.455	1.524	
Fe	0.002	0.000	0.002	0.002	0.000	0.002	0.000	0.002	0.002	0.002	0.000	0.002	0.005	
Ca	0.396	0.437	0.442	0.457	0.393	0.449	0.448	0.660	0.771	0.668	0.951	0.450	0.524	
Ba	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.003	0.002	0.000	0.004	0.000	0.001	
Na	0.600	0.552	0.564	0.540	0.595	0.537	0.551	0.349	0.237	0.358	0.057	0.488	0.000	
K	0.005	0.003	0.004	0.004	0.004	0.005	0.004	0.000	0.000	0.000	0.000	0.003	0.000	
TOTAL	5.002	4.994	5.007	5.002	4.994	4.991	5.001	5.007	5.007	5.016	5.009	5.008	5.011	
PLAG END MEMBERS														
Or	0.5	0.3	0.4	0.4	0.4	0.5	0.4	0.0	0.0	0.0	0.0	0.3	0.0	
Ab	59.9	55.5	55.8	53.9	60.0	54.2	54.9	34.5	23.5	34.8	5.6	55.0	48.2	
An	39.6	44.0	43.8	45.7	39.6	45.3	44.7	65.2	76.4	65.0	94.0	44.7	51.7	

* All Fe calculated as Fe2O3
na - Not analyzed

PLAGIOCLASE ANALYSES
SAMPLE: 83LGM122 (cont.)

NOTES:		INCLUSIONS w/in mega G2										INCLUSIONS w/in mega G4									
POINT:		16	20	21	22	25	28	31	max.	2a	3a	4a	5a	max.	6a	7a	min.				
WT %	SiO2	52.20	46.98	55.90	53.14	52.80	46.48	45.25	45.55	43.72	45.27	44.76	54.44	55.34							
	Al2O3	30.32	33.68	27.66	29.39	29.42	33.41	34.57	34.50	35.73	34.51	35.01	28.28	27.78							
	Fe2O3 *	0.08	<0.05	<0.05	0.08	<0.05	<0.05	<0.05	0.07	0.07	<0.05	<0.05	<0.05	0.08							
	CaO	12.34	17.02	9.91	12.24	11.83	16.74	18.03	17.76	19.28	17.82	18.66	10.51	10.08							
	BaO	<0.05	0.15	<0.05	<0.05	0.11	0.17	<0.05	na	na	na	na	na	na							
	Na2O	4.36	1.92	6.02	4.69	4.74	1.95	1.26	1.38	0.51	1.29	0.91	5.55	5.84							
	K2O	<0.05	<0.05	0.05	<0.05	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	0.05							
	TOTAL	99.80	99.75	99.54	99.54	98.95	98.75	99.11	99.26	99.31	98.89	99.34	98.83	99.17							
CATIONS BASED ON 8 OXYGENS																					
	Si	2.371	2.164	2.524	2.415	2.414	2.162	2.103	2.112	2.035	2.107	2.078	2.481	2.510							
	Al	1.624	1.829	1.472	1.575	1.586	1.833	1.893	1.886	1.961	1.893	1.916	1.519	1.485							
	Fe	0.003	0.000	0.000	0.003	0.000	0.000	0.000	0.002	0.002	0.000	0.000	0.000	0.003							
	Ca	0.625	0.840	0.479	0.596	0.579	0.835	0.898	0.882	0.961	0.889	0.928	0.513	0.490							
	Ba	0.000	0.003	0.000	0.000	0.002	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000							
	Na	0.384	0.172	0.527	0.414	0.420	0.176	0.114	0.124	0.046	0.116	0.082	0.490	0.514							
	K	0.000	0.000	0.003	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003							
	TOTAL	5.007	5.008	5.005	5.003	5.004	5.009	5.008	5.006	5.005	5.005	5.004	5.006	5.005							
PLAG END MEMBERS																					
	Or	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3							
	Ab	38.1	16.9	52.2	41.1	41.8	17.4	11.3	12.3	4.6	11.5	8.1	48.7	51.0							
	An	61.9	82.8	47.5	59.0	57.7	82.3	88.7	87.7	95.4	88.5	91.9	51.0	48.7							

* Total Fe calculated as Fe2O3.
na - Not analyzed

PLAGIOCLASE ANALYSES
SAMPLE: 83LGM122 (cont.)

NOTES:		INCLUSIONS w/in mega G5		
POINT:		max. 10a	14a	min. 16a
WT %	SiO2	45.84	54.48	55.66
	Al2O3	33.85	27.96	27.87
	Fe2O3	<0.05	0.05	0.07
	CaO	17.56	10.51	9.87
	BaO	na	na	na
	Na2O	1.49	5.59	6.06
	K2O	<0.05	<0.05	<0.05
	TOTAL	98.74	98.59	99.53

CATIONS BASED ON 8 OXYGENS				
	Si	2.135	2.489	2.514
	Al	1.858	1.506	1.484
	Fe	0.000	0.002	0.002
	Ca	0.876	0.514	0.478
	Ba	0.000	0.000	0.000
	Na	0.134	0.495	0.530
	K	0.000	0.000	0.000
	TOTAL	5.003	5.006	5.008

PLAG END MEMBERS			
Or	0.0	0.0	0.0
Ab	13.3	49.1	52.6
An	86.7	50.9	47.4

* Total Fe calculated as Fe2O3.
na - Not analyzed

NOTES:	MEGACRYSTS	INCLUSIONS	
	twinned	w/in mega G1	w/in mega G2

CATIONS BASED ON 8 OXYGENS											
Si	2.562	2.597	2.585	2.594	2.586	2.096	2.582	2.587	2.169	2.131	2.104
Al	1.429	1.396	1.410	1.404	1.415	1.892	1.407	1.401	1.825	1.861	1.890
Fe	0.002	0.004	0.000	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.000
Ca	0.442	0.401	0.415	0.398	0.403	0.911	0.422	0.418	0.830	0.870	0.890
Ba	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Na	0.554	0.594	0.591	0.596	0.581	0.109	0.589	0.590	0.182	0.144	0.131
K	0.013	0.014	0.010	0.013	0.012	0.000	0.012	0.013	0.000	0.000	0.000
TOTAL	5.005	5.006	5.011	5.008	5.000	5.011	5.015	5.013	5.008	5.008	5.015

Si	2.562	2.597	2.585	2.594	2.586	2.096	2.582	2.587	2.169	2.131	2.104
Al	1.429	1.396	1.410	1.404	1.415	1.892	1.407	1.401	1.825	1.861	1.890
Fe	0.002	0.004	0.000	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.000
Ca	0.442	0.401	0.415	0.398	0.403	0.911	0.422	0.418	0.830	0.870	0.890
Ba	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Na	0.554	0.594	0.591	0.596	0.581	0.109	0.589	0.590	0.182	0.144	0.131
K	0.013	0.014	0.010	0.013	0.012	0.000	0.012	0.013	0.000	0.000	0.000

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 83MB18 (cont.)

NOTES:	INCLUSIONS		w/in mega G2				w/in mega G3				w/in mega G4			
	w/in mega G2		19	20	24	1a	3a	4a	5a	12a				
POINT:														
WT %	SiO2	54.19	54.82	53.05	52.17	45.25	44.01	45.86	46.64					
	Al2O3	28.08	27.64	29.26	29.48	34.21	34.96	33.75	33.53					
	Fe2O3 *	0.07	0.11	0.10	0.12	<0.05	<0.05	0.08	0.07					
	CaO	10.75	10.13	11.84	12.85	18.32	19.20	18.03	16.67					
	BaO	<0.05	0.08	<0.05	na	na	na	na	na					
	Na2O	5.54	5.79	4.84	4.35	1.06	0.62	1.36	1.91					
	K2O	0.09	0.12	0.10	0.08	<0.05	<0.05	<0.05	0.05					
	TOTAL	98.72	98.69	99.19	99.05	98.84	98.79	99.08	98.87					
CATIONS BASED ON 8 OXYGENS														
	Si	2.478	2.505	2.421	2.390	2.109	2.059	2.131	2.164					
	Al	1.513	1.489	1.574	1.592	1.880	1.928	1.849	1.835					
	Fe	0.000	0.000	0.000	0.004	0.000	0.000	0.003	0.003					
	Ca	0.527	0.496	0.579	0.631	0.915	0.962	0.898	0.829					
	Ba	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
	Na	0.491	0.513	0.429	0.386	0.096	0.056	0.123	0.172					
	K	0.005	0.007	0.006	0.005	0.000	0.000	0.000	0.003					
	TOTAL	5.014	5.010	5.009	5.008	5.000	5.005	5.004	5.006					
PLAG END MEMBERS														
	Or	0.5	0.7	0.6	0.5	0.0	0.0	0.0	0.3					
	Ab	48.0	48.8	42.3	37.8	9.5	5.5	12.0	17.1					
	An	51.5	50.5	57.1	61.7	90.5	94.5	88.0	82.6					

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 90LGM39 MASSIVE ANORTHOSITE

NOTES:	MEGACRYST	INCLUSIONS w/in mega g1 blade				FINE (<0.3)			
GRAIN SIZE (mm):	(4.7)								
# PTS. ANALYZED:	3								
POINT:	max. G1-8	min. G1-7	1	4	6	min. 9a	max. 10	max. 14	min. 11
WT %									
SiO2	58.03	58.30	44.25	45.15	44.55	44.99	42.78	43.09	43.57
Al2O3	26.03	26.17	35.34	34.31	34.89	34.97	35.43	36.41	35.70
Fe2O3 *	0.06	<0.05	0.05	<0.05	<0.05	0.06	<0.05	<0.05	<0.05
CaO	8.24	8.08	18.92	18.18	18.74	18.37	19.50	19.82	19.22
SrO	0.08	0.12	<0.05	0.05	<0.05	0.06	<0.05	<0.05	<0.05
BaO	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Na2O	6.91	6.97	0.84	1.18	0.84	1.11	0.30	0.20	0.53
K2O	0.08	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
TOTAL	99.43	99.69	99.40	98.87	99.02	99.56	98.01	99.52	99.02

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CATIONS BASED ON 8 OXYGENS									
Si	2.611	2.614	2.056	2.105	2.076	2.084	2.020	2.004	2.034
Al	1.381	1.384	1.936	1.885	1.917	1.910	1.973	1.997	1.965
Fe	0.002	0.000	0.002	0.000	0.000	0.002	0.000	0.000	0.000
Ca	0.397	0.388	0.942	0.908	0.936	0.912	0.987	0.988	0.961
Sr	0.002	0.003	0.000	0.001	0.000	0.002	0.000	0.000	0.000
Ba	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Na	0.603	0.606	0.076	0.106	0.076	0.100	0.027	0.018	0.048
K	0.005	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL	5.001	4.998	5.012	5.005	5.005	5.010	5.007	5.007	5.008
PLAG END MEMBERS									
Or	0.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ab	59.9	60.6	7.5	10.4	7.5	9.9	2.7	1.8	4.8
An	39.4	38.8	92.5	89.5	92.5	89.9	97.3	98.2	95.2

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 86MBGA MASSIVE ANORTHOSSITE

ES:	MEGACRYSTS				INCLUSIONS				INCLUSIONS				FINE			
					w/in mega G1				w/in mega G2				adjacent to			
GRAIN SIZE (mm):	(3.0)				(9.0)								mega			
													(<0.3)			
# PTS. ANALYZED:	4	3														
POINT:	max. G1-6	min. G1-13	max. G2-14	min. G2-16	max. 7	9	min. 10	11	18	21	min. G3-1	G7-12	G8-24			
WT %	SiO2	56.93	58.67	57.11	44.01	44.49	44.72	44.33	44.77	43.85	57.52	54.63	51.42			
	Al2O3	27.10	26.22	26.32	35.41	35.61	34.83	35.49	34.98	35.14	26.51	28.39	30.72			
	Fe2O3 *	0.06	0.06	0.10	0.06	0.11	0.05	0.08	<0.05	<0.05	<0.05	<0.05	0.09			
	CaO	9.00	7.95	8.42	19.10	18.96	18.53	18.95	18.56	19.84	8.50	10.65	13.46			
	BaO	0.12	<0.05	0.07	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	<0.05	<0.05			
	Na2O	6.43	7.03	6.78	0.65	0.75	1.01	0.76	0.85	0.76	6.91	5.47	3.92			
	K2O	0.08	0.05	0.09	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	<0.05	<0.05			
	TOTAL	99.72	99.98	98.89	99.23	99.92	99.14	99.61	99.22	99.59	99.51	99.14	99.61			
CATIONS BASED ON 8 OXYGENS																
	Si	2.561	2.620	2.588	2.049	2.056	2.081	2.055	2.081	2.041	2.589	2.480	2.344			
	Al	1.437	1.380	1.406	1.944	1.940	1.911	1.940	1.917	1.929	1.406	1.519	1.651			
	Fe	0.002	0.002	0.003	0.002	0.004	0.002	0.003	0.000	0.000	0.000	0.001	0.003			
	Ca	0.434	0.380	0.409	0.953	0.939	0.924	0.941	0.924	0.990	0.410	0.518	0.657			
	Ba	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000			
	Na	0.561	0.609	0.596	0.059	0.067	0.091	0.068	0.077	0.069	0.603	0.481	0.346			
	K	0.004	0.003	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.003	0.000			
	TOTAL	4.999	4.994	5.008	5.007	5.006	5.009	5.007	5.000	5.029	5.012	5.002	5.001			
PLAG END MEMBERS																
	Or	0.4	0.3	0.5	0.0	0.0	0.1	0.0	0.0	0.0	0.4	0.3	0.0			
	Ab	56.2	61.4	59.0	5.8	6.7	9.0	6.7	7.7	6.5	59.3	48.0	34.5			
	An	43.4	38.3	40.5	94.2	93.3	91.0	93.3	92.2	93.5	40.3	51.7	65.5			

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 86MB6A (cont.)

NOTES:		FINE									
GRAIN SIZE (mm):		(<0.3)									
POINT:		G9-25	G1-26	max. G11-28	G12-31	G13-32	G14-33	G15-34	G16-38	G17-39	
WT %	SiO2	52.69	52.05	47.71	51.96	51.41	54.68	52.15	52.55	52.07	
	Al2O3	29.92	29.93	32.68	30.16	30.54	28.88	29.85	29.66	29.68	
	Fe2O3 *	0.05	0.05	0.12	0.07	0.09	<0.05	<0.05	<0.05	<0.05	
	CaO	12.56	12.72	15.81	12.74	13.27	11.19	12.65	12.41	12.42	
	BaO	<0.05	<0.05	<0.05	<0.05	0.22	<0.05	0.15	<0.05	<0.05	
	K2O	4.46	4.34	2.51	4.29	3.92	5.20	4.42	4.64	4.59	
	Na2O	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	0.06	
	TOTAL	99.68	99.09	98.83	99.22	99.45	99.95	99.22	99.31	98.82	
CATIONS BASED ON 8 OXYGENS											
	Si	2.393	2.380	2.210	2.373	2.350	2.465	2.384	2.397	2.388	
	Al	1.602	1.614	1.785	1.624	1.646	1.535	1.609	1.595	1.605	
	Fe	0.002	0.002	0.004	0.002	0.003	0.000	0.000	0.000	0.000	
	Ca	0.611	0.623	0.785	0.624	0.650	0.541	0.620	0.607	0.610	
	Ba	0.000	0.000	0.000	0.000	0.004	0.000	0.003	0.000	0.000	
	K	0.393	0.385	0.226	0.379	0.347	0.454	0.392	0.410	0.408	
	Na	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003	
	TOTAL	5.001	5.004	5.010	5.002	5.000	4.995	5.008	5.012	5.014	
PLAG END MEMBERS											
	Or	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	
	Ab	39.1	38.2	22.4	37.8	34.7	45.6	38.6	40.2	40.0	
	An	60.9	61.8	77.6	62.2	64.9	54.4	61.1	59.2	59.7	

* Total Fe calculated as Fe2O3.

APPENDIX B
Sheared Anorthosite
Plagioclase Analyses

PLAGIOCLASE ANALYSES
SAMPLE: 90LGM18B SHEARED ANORTHOSITE

NOTES:	MEGACRYSTS twinned (2.3)			(2.5)			INCLUSIONS w/in mega G2					FINE adjacent to mega (0.03-0.13)		
GRAIN SIZE (mm):														
# PTS. ANALYZED:	3			6										
POINT:	min. G1-4	max. G1-5	max. G2-13	min. G2-17	11	12	15	16	19	20	G3-1	G4-2		
WT %														
SiO2	56.09	55.86	57.69	58.22	44.80	44.68	44.87	44.38	44.44	44.14	51.34	51.39		
Al2O3	27.20	27.36	26.73	26.36	34.87	34.88	35.02	35.51	35.55	35.82	30.87	30.87		
Fe2O3 *	<0.05	<0.05	0.05	<0.05	0.11	0.08	0.14	<0.05	0.06	0.05	0.09	0.10		
CaO	9.07	9.22	8.51	7.89	18.13	18.18	18.34	18.72	18.72	19.03	13.30	13.24		
SrO	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		
BaO	0.07	<0.05	0.17	<0.05	0.23	<0.05	<0.05	<0.05	<0.05	<0.05	0.12	<0.05		
Na2O	6.39	6.20	6.79	7.15	1.14	1.15	1.10	0.95	0.91	0.68	4.00	4.07		
K2O	0.06	<0.05	0.08	0.08	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		
TOTAL	98.88	98.64	100.02	99.70	99.28	98.97	99.47	99.56	99.68	99.72	99.72	99.67		
CATIONS BASED ON 8 OXYGENS														
Si	2.546	2.539	2.585	2.609	2.083	2.081	2.080	2.058	2.058	2.044	2.340	2.341		
Al	1.456	1.466	1.412	1.393	1.912	1.916	1.914	1.941	1.941	1.956	1.658	1.658		
Fe	0.000	0.000	0.002	0.000	0.004	0.003	0.005	0.000	0.002	0.002	0.003	0.003		
Ca	0.441	0.449	0.409	0.379	0.904	0.908	0.911	0.930	0.929	0.944	0.650	0.646		
Sr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
Ba	0.001	0.000	0.003	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.002	0.000		
Na	0.563	0.547	0.590	0.621	0.103	0.104	0.099	0.085	0.082	0.061	0.354	0.359		
K	0.003	0.000	0.004	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
TOTAL	5.010	5.001	5.005	5.007	5.010	5.012	5.009	5.014	5.012	5.007	5.007	5.007		
PLAG END MEMBERS														
Or	0.3	0.0	0.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Ab	55.9	54.9	58.6	61.8	10.2	10.3	9.8	8.5	8.1	6.1	35.2	35.7		
An	43.8	45.1	40.7	37.7	89.4	89.7	90.2	91.5	91.9	93.9	64.6	64.3		

Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 90LGM18C SHEARED ANORTHOISITE

NOTES:	MEGACRYSTS		INCLUSIONS w/in mega G1		MEDIUM		FINE						
# PTS. ANALYZED:	7				4								
POINT:	min. G1-1	max. G1-12	2	8	min. G2-24	max. G2-28	min. G3-21	G4-22	G5-23	max. G6-30	G7-52	G8-53	
WT %													
SiO2	57.79	56.45	49.41	51.72	56.82	55.95	56.84	57.45	57.11	51.55	55.98	56.36	
Al2O3	26.50	27.14	32.02	30.39	26.81	27.28	26.89	26.70	26.63	30.27	27.00	26.99	
Fe2O3 *	<0.05	0.07	0.09	<0.05	0.06	<0.05	<0.05	<0.05	0.05	<0.05	0.08	0.09	
CaO	8.51	9.24	15.05	13.09	8.35	9.00	8.41	8.42	8.21	12.47	8.51	8.62	
SrO	0.05	0.06	0.06	0.05	<0.05	<0.05	0.06	0.05	<0.05	<0.05	<0.05	<0.05	
BaO	0.11	0.15	0.05	<0.05	<0.05	<0.05	<0.05	0.10	<0.05	<0.05	0.21	<0.05	
Na2O	6.74	6.37	2.91	4.00	6.74	6.38	6.85	6.74	6.98	4.37	6.78	6.66	
K2O	0.10	<0.05	<0.05	0.05	0.06	0.09	0.08	0.08	0.09	<0.05	0.06	0.07	
TOTAL	99.80	99.48	99.59	99.30	98.84	98.70	99.13	99.54	99.07	98.66	98.62	98.79	
CATIONS BASED ON 8 OXYGENS													
Si	2.594	2.549	2.265	2.362	2.574	2.543	2.570	2.585	2.581	2.367	2.550	2.558	
Al	1.403	1.445	1.730	1.637	1.431	1.462	1.433	1.416	1.419	1.638	1.450	1.444	
Fe	0.000	0.002	0.003	0.000	0.002	0.000	0.000	0.000	0.002	0.000	0.003	0.003	
Ba	0.409	0.447	0.739	0.641	0.405	0.438	0.408	0.406	0.398	0.614	0.415	0.419	
Sr	0.001	0.002	0.002	0.001	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000	
Ba	0.002	0.003	0.001	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.004	0.000	
Na	0.586	0.558	0.258	0.354	0.592	0.562	0.600	0.588	0.612	0.398	0.599	0.586	
K	0.006	0.000	0.000	0.003	0.003	0.005	0.004	0.005	0.005	0.000	0.003	0.004	
TOTAL	5.001	5.006	4.998	4.998	5.007	5.010	5.017	5.003	5.017	5.017	5.024	5.014	
PLAG END MEMBERS													
Or	0.6	0.3	0.0	0.3	0.3	0.5	0.4	0.5	0.5	0.0	0.3	0.4	
Ab	58.4	55.0	25.8	35.4	59.2	55.9	59.2	58.7	60.3	39.3	58.7	58.1	
An	40.7	44.2	73.9	64.2	40.5	43.6	40.2	40.5	39.2	60.7	40.6	41.5	

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 90LGM18D SHEARED ANORTHOSSITE

NOTES:		MEGACRYST		FINE in laminae (0.03-0.13)													
GRAIN SIZE (mm):																	
# PTS. ANALYZED:	6	min. G1-34	max. G1-40	max. 1	2	3	4	5	6	7	8	9	12				
POINT:																	
WT %	SiO2	58.38	57.79	43.07	44.36	43.19	43.76	44.15	44.30	46.03	45.42	50.96	43.61				
	Al2O3	26.10	26.53	35.67	34.64	35.83	35.84	35.21	34.99	33.91	34.27	31.10	35.67				
	Fe2O3 *	<0.05	<0.05	0.09	0.11	0.07	0.05	0.05	0.04	0.05	0.08	<0.05	0.08				
	CaO	8.03	8.43	20.03	19.06	19.67	19.70	19.31	19.15	17.71	18.18	13.77	19.59				
	SrO	<0.05	<0.05	<0.05	<0.05	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	<0.05				
	BaO	0.00	<0.05	<0.05	<0.05	0.08	0.07	<0.05	<0.05	<0.05	0.08	0.12	<0.05				
	Na2O	6.97	6.72	0.23	0.82	0.42	0.45	0.60	0.82	1.53	1.29	3.87	0.48				
	K2O	0.07	0.08	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05				
TOTAL		99.55	99.55	99.09	98.99	99.33	99.87	99.32	99.30	99.23	99.32	99.87	99.43				

CATIONS BASED ON 8 OXYGENS

Si	2.619	2.596	2.015	2.073	2.016	2.029	2.055	2.063	2.134	2.109	2.323	2.030
Al	1.380	1.405	1.967	1.908	1.972	1.959	1.932	1.920	1.853	1.876	1.671	1.958
Fe	0.000	0.000	0.003	0.004	0.002	0.002	0.002	0.001	0.002	0.003	0.000	0.003
Ca	0.386	0.406	1.004	0.949	0.984	0.979	0.963	0.955	0.880	0.904	0.673	0.977
Sr	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Ba	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000	0.000	0.002	0.002	0.000
Na	0.606	0.586	0.021	0.074	0.038	0.041	0.054	0.074	0.138	0.116	0.342	0.043
K	0.004	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL	4.995	4.997	5.010	5.008	5.016	5.012	5.006	5.013	5.007	5.010	5.012	5.011

PLAG END MEMBERS

Or	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ab	60.8	58.8	2.0	7.2	3.7	4.0	5.3	7.2	13.6	11.4	33.6	4.2
An	38.8	40.8	98.0	92.8	95.9	95.8	94.7	92.8	86.4	88.5	66.1	95.8

* Total Fe calculated as Fe2O3.

APPENDIX C
Foliated Anorthosite
Plagioclase Analyses

PLAGIOCLASE ANALYSES
SAMPLE: 83LGM70 FOLIATED ANORTHOSSITE

NOTES:		MEGACRYSTS		INCLUSIONS		w/in mega G1		w/in mega G2		MEDIUM w/in garnet (0.6)		MEDIUM (0.5)	
GRAIN SIZE (mm):		(2.0)		(1.4)									
# PTS. ANALYZED:		5	min.	max.	2	min.	max.	4	6	7	28	3	
POINT:		G1-3	G1-11	G2-29	G2-30	G2-30	G2-30	G3-13	G3-15	G4-16	G4-17		
WT %	SiO2	58.20	57.48	57.94	57.69	44.22	45.77	44.21	44.05	58.18	58.29	57.49	57.89
	Al2O3	26.12	26.32	26.13	26.54	35.21	34.28	34.76	35.21	26.07	26.06	26.60	26.39
	Fe2O3 *	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.10	<0.05	0.09	0.05	<0.05	0.15
	CaO	8.06	8.37	7.90	8.21	18.77	17.68	18.65	18.82	7.79	7.89	8.56	8.11
	BaO	0.13	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.06
	Na2O	7.01	6.77	7.01	6.89	0.83	1.49	0.87	0.85	7.07	7.16	6.73	6.94
	K2O	0.13	0.10	0.13	0.13	<0.05	<0.05	<0.05	<0.05	0.14	0.11	0.14	0.13
TOTAL		99.65	99.10	99.11	99.46	99.03	99.22	98.59	98.93	99.34	99.56	99.52	99.67

CATIONS BASED ON 8 OXYGENS

Si	2.613	2.596	2.612	2.595	2.061	2.122	2.070	2.057	2.617	2.587	2.600
Al	1.383	1.402	1.389	1.407	1.935	1.874	1.919	1.938	1.383	1.411	1.397
Fe	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.003	0.000	0.005
Ca	0.388	0.405	0.382	0.396	0.938	0.878	0.936	0.941	0.376	0.379	0.390
Ba	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Na	0.610	0.593	0.613	0.601	0.075	0.134	0.079	0.077	0.617	0.623	0.604
K	0.008	0.006	0.008	0.008	0.000	0.000	0.000	0.000	0.008	0.006	0.007
TOTAL		5.004	5.003	5.004	5.007	5.009	5.008	5.013	5.004	5.006	5.004

PLAG END MEMBERS

Or	0.8	0.6	0.8	0.8	0.0	0.0	0.0	0.0	0.8	0.6	0.7
Ab	60.5	59.0	61.1	59.8	7.4	13.2	7.8	7.6	61.6	58.2	60.3
An	38.5	40.3	38.1	39.4	92.6	86.8	92.2	92.5	37.6	41.0	38.9

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 83LGH70 (cont.)

NOTES:	MEDIUM	FINE	FINE in Laminæ (0.03-0.13)
GRAIN SIZE (mm):	(0.7)	(0.13-0.5)	
# PTS. ANALYZED:	3		
	max. G5-23	min. G5-24	max. G9-12
			min. G10-20
			G11-10
WT %			
SiO ₂	57.16	57.38	54.94
Al ₂ O ₃	26.80	26.61	28.04
Fe ₂ O ₃ *	0.05	0.06	<0.05
CaO	8.86	8.35	10.17
BaO	<0.05	0.15	0.08
Na ₂ O	6.53	6.69	5.85
K ₂ O	0.09	0.10	0.07
TOTAL	99.49	99.34	99.15
			99.37
			100.09
			99.09
			99.78
CATIONS BASED ON 8 OXYGENS			
Si	2.574	2.587	2.496
Al	1.423	1.414	1.502
Fe	0.002	0.002	0.000
Ca	0.428	0.403	0.495
Ba	0.000	0.003	0.001
Na	0.570	0.585	0.515
K	0.005	0.006	0.004
TOTAL	5.002	5.000	5.013
			5.017
			5.011
			5.015
			5.003
PLAG END MEMBERS			
Or	0.5	0.6	0.4
Ab	56.8	58.7	50.7
An	42.7	40.4	48.8
			56.1
			81.6
			91.6
			65.4
			0.6
			34.0
			65.4

* Total Fe calculated as Fe₂O₃.

APPENDIX D
Plagioclase (+/- Quartz) Veins
Plagioclase Analyses

PLAGIOCLASE ANALYSES
SAMPLE: 83MB38 PLAG-RICH VEIN

NOTES:		MEGACRYSTS		MEDIUM		FINE	
GRAIN SIZE (mm):		(9.3)		(1.5)		(0.3)	
# PTS. ANALYZED:	5	max.	min.	3	max.	6	min.
POINT:	G1-11	G1-15	G2-7	G3-1	G3-3		
WT %	SiO2	60.59	62.12	60.78	61.67	60.45	61.05
	Al2O3	24.51	23.38	24.45	24.21	24.52	24.36
	Fe2O3 *	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	CaO	6.07	4.68	5.71	5.54	5.99	5.40
	BaO	<0.05	<0.05	<0.05	<0.05	0.07	<0.05
	Na2O	8.07	8.94	8.15	8.53	8.33	8.45
	K2O	0.12	0.13	0.10	0.11	0.10	0.10
	TOTAL	99.36	99.25	99.19	100.06	99.46	99.36
CATIONS BASED ON 8 OXYGENS							
	Si	2.709	2.771	2.718	2.734	2.704	2.725
	Al	1.292	1.229	1.289	1.266	1.293	1.282
	Fe	0.000	0.000	0.000	0.000	0.000	0.000
	Ca	0.291	0.224	0.273	0.263	0.287	0.258
	Ba	0.000	0.000	0.000	0.000	0.001	0.000
	Na	0.700	0.773	0.707	0.734	0.723	0.731
	K	0.007	0.007	0.006	0.006	0.006	0.006
	TOTAL	4.999	5.004	4.993	5.003	5.014	5.002
PLAG END MEMBERS							
	Or	0.7	0.7	0.6	0.6	0.6	0.6
	Ab	70.1	77.0	71.7	73.2	71.2	73.5
	An	29.2	22.3	27.7	26.2	28.2	25.9

* Total Fe calculated as Fe2O3.

PLAGIOCLASE ANALYSES
SAMPLE: 83MB33 PLAG-RICH VEIN

NOTES:		MEDIUM		FINE	
GRAIN SIZE (mm):		(0.5-2.0)		(0.13-0.5)	
# PTS. ANALYZED:	16	9			
POINTS:	max.	min.	max.	min.	
	G6-22	G7-23	G16-8	G13-5	
WT %	SiO ₂	57.31	58.53	57.30	58.28
	Al ₂ O ₃	26.62	25.78	26.85	25.93
	Fe ₂ O ₃ *	<0.05	<0.05	<0.05	<0.05
	CaO	8.43	7.53	8.57	7.76
	BaO	<0.05	<0.05	0.12	<0.05
	Na ₂ O	6.62	7.27	6.63	7.21
	K ₂ O	0.10	0.10	0.08	0.10
	TOTAL	99.08	99.21	99.55	99.28

CATIONS BASED ON 8 OXYGENS					
	Si	2.587	2.633	2.578	2.623
	Al	1.417	1.367	1.424	1.376
	Fe	0.000	0.000	0.000	0.000
	Ca	0.408	0.363	0.413	0.374
	Ba	0.000	0.000	0.002	0.000
	Na	0.580	0.634	0.579	0.629
	K	0.006	0.006	0.005	0.006
	TOTAL	4.998	5.003	5.001	5.008

PLAG END MEMBERS					
	Or	0.6	0.6	0.5	0.6
	Ab	58.4	63.2	58.1	62.3
	An	41.0	36.2	41.4	37.1

* Total Fe calculated as Fe₂O₃.

APPENDIX E
Amphibole Analyses

AMPHIBOLE ANALYSES		83LGM122	90LGM180	90LGM180	83MB44	90LGM37A	86MB6A
SAMPLE:		massive	sheared	sheared	massive	massive	massive
NOTES:							
# PTS ANALYZED:		23	4	2	16	5	6
WT %							
SiO2	40.7 (8) ***	42.0 (10)	52.7 (5)	42.8 (10)	45.3 (8)	41.4 (3)	
Al2O3	16.5 (12)	14.8 (11)	2.74 (67)	16.9 (10)	11.6 (10)	17.6 (7)	
TiO2	0.39 (15)	0.12 (3)	<0.05 (0)	0.39 (7)	0.63 (15)	0.41 (6)	
MgO	9.92 (53)	10.6 (8)	18.7 (4)	11.4 (6)	13.0 (6)	10.9 (4)	
MnO	0.15 (5)	0.94 (9)	3.40 (30)	0.15 (5)	0.14 (2)	0.18 (5)	
FeO *	15.0 (10)	15.6 (4)	17.2 (4)	11.8 (7)	13.1 (7)	12.2 (12)	
BaO	<0.05 (0)	<0.05 (0)	0.18 (2)	<0.05 (0)	<0.05 (0)	<0.05 (0)	
CaO	11.1 (16)	10.9 (3)	2.13 (80)	11.7 (2)	11.8 (1)	11.6 (2)	
Na2O	1.53 (12)	1.24 (7)	0.27 (9)	1.56 (5)	1.08 (10)	1.30 (4)	
K2O	0.41 (5)	0.31 (7)	<0.05 (0)	0.48 (7)	0.22 (4)	0.62 (9)	
<H2O> **	1.98 (2)	1.99 (1)	2.06 (0)	2.03 (1)	2.04 (1)	1.96 (1)	
<F>	<0.05 (0)	<0.05 (0)	<0.05 (0)	<0.05 (0)	<0.05 (0)	<0.05 (0)	
<Cl>	<0.05 (0)	<0.05 (0)	<0.05 (0)	0.09 (4)	<0.05 (0)	0.22 (6)	
TOTAL	97.68	98.50	99.38	99.30	98.91	98.39	
CATIONS BASED ON 23 OXYGENS							
Si	6.147	6.313	7.674	6.254	6.670	6.131	
Al	2.932	2.627	0.471	2.906	2.005	3.075	
Ti	0.044	0.014	0.000	0.043	0.070	0.046	
Mg	2.235	2.371	4.051	2.073	2.859	2.405	
Mn	0.019	0.120	0.420	0.019	0.017	0.023	
Fe	1.897	1.958	2.094	1.443	1.606	1.506	
Ba	0.000	0.000	0.010	0.000	0.000	0.000	
Ca	1.805	1.750	0.332	1.936	1.855	1.832	
Na	0.449	0.361	0.076	0.442	0.308	0.373	
K	0.079	0.059	0.000	0.090	0.041	0.117	
TOTAL	15.607	15.573	15.128	15.160	15.431	15.508	
<OH>	1.997	1.996	2.002	1.980	2.002	1.936	
<F>	0.000	0.000	0.000	0.000	0.000	0.000	
<Cl>	0.000	0.000	0.000	0.022	0.000	0.005	
Mg#	0.54	0.55	0.66	0.59	0.64	0.61	

* All Fe calculated as Fe2+.

** H2O calculated assuming (OH, F, Cl) = 2 moles.

*** Units in () represent one standard deviation of replicate analyses.

APPENDIX F
Mica Analyses

AVERAGE MICA ANALYSES

SAMPLE:		83MB39 massive	84LGM115 foliated	83LGM70 foliated
# PTS. ANALYZES:	23	4	7	
WT %	SiO2	34.9 (5) ***	45.0 (5)	43.7 (6)
	Al2O3	19.7 (2)	34.8 (3)	34.1 (6)
	TiO2	1.75 (11)	0.27 (8)	0.60 (14)
	Cr2O3	<0.05 (0)	<0.05 (0)	<0.05 (0)
	MgO	8.56 (64)	1.37 (19)	0.81 (19)
	MnO	<0.05 (0)	<0.05 (0)	<0.05 (0)
	FeO *	20.6 (10)	2.14 (23)	2.60 (44)
	CaO	<0.05 (0)	<0.05 (0)	0.05 (5)
	BaO	<0.05 (0)	0.11 (8)	0.85 (29)
	Na2O	0.24 (4)	0.26 (4)	0.76 (11)
	K2O	8.99 (12)	10.5 (3)	9.80 (25)
	<H2O> **	3.84 (4)	4.40 (4)	4.32 (3)
	<F>	0.11 (6)	0.05 (5)	<0.05 (0)
	<Cl>	<0.05 (0)	<0.05 (0)	<0.05 (0)
	-O = F	98.69	98.90	97.59
		0.05	0.02	0.90
	TOTAL	98.64	98.88	97.59
CATIONS BASED ON 22 OXYGENS				
	Si	5.359	6.075	6.036
	Al	3.557	5.552	5.550
	Ti	0.202	0.027	0.062
	Cr	0.000	0.000	0.000
	Mg	1.959	0.276	0.167
	Mn	0.000	0.000	0.001
	Ca	0.000	0.002	0.007
	Fe	2.647	0.242	0.300
	Ba	0.000	0.006	0.046
	Na	0.071	0.068	0.204
	K	1.761	1.810	1.728
	TOTAL	15.556	14.056	14.038
	<OH>	3.933	3.967	3.982
	<F>	0.053	0.021	0.000
	<Cl>	0.000	0.000	0.000
Mg#		0.43	0.53	0.36

* All Fe calculated as Fe2+.

** H2O calculated assuming (OH, F, CL) = 4 moles.

*** Units in () represent one standard deviation of replicate analyses.

APPENDIX G
Garnet Analyses

AVERAGE GARNET ANALYSES			
SAMPLE:		90LGM70 foliated	83MB39 massive
# PTS. ANALYZED:	12	15	9
WT %			
SiO2	36.9 (5) **	38.3 (1)	37.0 (3)
TiO2	<0.05 (0)	<0.05 (0)	<0.05 (0)
Al2O3	21.5 (2)	21.7 (0)	21.6 (1)
Cr2O3	<0.05 (0)	<0.05 (2)	<0.05 (0)
Fe2O3 *	2.42 (0)	1.73 (9)	2.01 (0)
MgO	5.25 (63)	6.61 (10)	6.10 (31)
CaO	5.31 (29)	6.81 (28)	2.79 (40)
MnO	3.55 (33)	1.52 (4)	0.15 (5)
FeO	24.4 (8)	25.3 (3)	29.7 (3)
TOTAL	99.02	100.30	99.15
CATIONS BASED ON 12 OXYGENS			
Si	2.924	2.955	2.933
Ti	0.000	0.000	0.000
Al	2.006	1.990	2.014
Cr	0.000	0.000	0.000
Fe3+	0.145	0.100	0.120
Mg	0.620	0.761	0.720
Ca	0.451	0.564	0.237
Mn	0.238	0.099	0.010
Fe2+	1.616	1.531	1.967
TOTAL	8.001	8.000	8.001
GARNET END MEMBERS			
Gr	14.7	18.5	7.8
Py	20.2	25.0	23.6
Sp	7.8	3.3	0.3
Al	57.4	53.3	68.3

* Fe3+ calculated by stoichiometry.

** Units in () represent one standard deviation of replicate analyses.

APPENDIX H
Chlorite Analyses

AVERAGE CHLORITE ANALYSES									
SAMPLE: 83LGM70 90LGM18C 90LGM18C 90LGM18C 86MB68 83LGM122 84LGM115									
# PTS. ANALYZED:	foliated	sheared	sheared	sheared	massive	massive	massive	schist	
	2	3	4	7	9	4	5		
wt %									
SiO2	24.4 (0) **	25.5 (2)	25.3 (2)	27.0 (5)	25.3 (9)	26.5 (3)	24.8 (5)		
TiO2	<0.05 (0)	<0.05 (0)	<0.05 (0)	<0.05 (1)	0.07 (3)	<0.05 (0)	0.07 (4)		
Al2O3	20.6 (0)	19.3 (3)	19.4 (0)	18.6 (2)	20.5 (4)	19.4 (0)	20.5 (5)		
MgO	13.9 (0)	15.7 (10)	15.7 (0)	19.0 (2)	18.8 (10)	18.8 (0)	12.4 (3)		
MnO	0.85 (3)	0.18 (3)	0.24 (3)	0.22(12)	0.15 (3)	0.08 (3)	0.37 (1)		
FeO *	25.4 (3)	24.2 (3)	25.1 (3)	21.0 (5)	19.5 (9)	21.0 (10)	26.5 (25)		
<H2O>	11.0 (0)	11.0 (1)	11.1 (4)	11.4 (9)	11.3 (2)	11.4 (7)	11.0 (4)		
TOTAL	96.05	95.84	96.87	97.13	95.48	97.19	95.64		
CATIONS BASED ON 28 OXYGENS									
Si	5.343	5.542	5.467	5.688	5.388	5.585	5.423		
Ti	0.000	0.000	0.000	0.000	0.012	0.000	0.026		
Al	5.318	4.941	4.939	4.619	5.147	4.811	5.297		
Mg	4.522	5.074	5.065	5.955	5.978	5.894	4.050		
Mn	0.158	0.033	0.044	0.039	0.027	0.014	0.069		
Fe	4.657	4.400	4.545	3.701	3.476	3.705	5.063		
TOTAL	19.997	19.990	20.060	20.002	20.028	20.009	19.928		
<OH>	16.002	16.996	16.007	16.000	16.000	16.000	16.000		
Mg#	0.49	0.54	0.53	0.62	0.63	0.61	0.44		

* All Fe calculated as FeO.

** Units in () represent one standard deviation of replicate analyses.

VITA

Karen Walker was born in Charlotte, North Carolina, in 1966 and graduated from Garinger High School, in 1984. She first became interested in geology as an Earth Science major at the University of North Carolina at Charlotte. After graduating in 1989 with a Bachelor of Science degree, Karen decided to pursue a Master of Science degree in Geology at the University of Tennessee, Knoxville. She graduated in 1993, and is currently employed as a Hydrogeologist with the Division of Environmental Management, State of North Carolina.