

**PETROLOGIC AND FLUID INCLUSION CONSTRAINTS ON THE
TECTONIC EVOLUTION OF THE MANHATTAN PRONG,
SOUTHEASTERN NEW YORK**

by

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(ABSTRACT)

The results of a combined mineral equilibria and fluid inclusion study show that the Manhattan Prong, southeastern New York, has experienced multiple metamorphic events. Two episodes of intrusion, separated by approximately 100 million years, have superimposed contact aureoles on the Taconic regional metamorphic gradient in the northeastern Manhattan Prong and have modified the regional assemblage to different degrees.

The assemblage Sil-Bt-Grt-Qtz-Pl±Ksp±Ms in regionally metamorphosed Manhattan Schist records P-T conditions of 4-5 kbar and 650-700 °C. Garnet porphyroblasts, homogenous with respect to major elements but zoned with respect to P and Y, contain ubiquitous, primary, CO₂-rich fluid inclusions which have a Th = 10-24 °C. Manhattan Schist collected adjacent to the Croton Falls and Peach Lake mafic complexes, intrusions thought to be related to the Late Ordovician Cortlandt Complex, record P-T estimates of 4 kbar and 700 °C and 4.2 kbar and 550-600 °C respectively. The lack of fluid inclusions in garnet porphyroblasts indicates that the regional metamorphic assemblage has been completely modified by the contact effects of the mafic intrusions. However, the presence of Ky+Sta along with the slight compositional zoning of garnets in Peach Lake samples suggests that the contact assemblage may have been modified by a later metamorphism.

Manhattan Schist collected adjacent to ~350 Ma granites (Brock, 1993) has been partially modified by contact metamorphism and shearing but vestiges of the regional metamorphic assemblage remain. Garnet porphyroblasts contain abundant CO₂-rich fluid inclusions and P-T estimates using Bt and Pl inclusions and garnet core compositions are

similar to estimates of regional metamorphic conditions. Evidence of modification includes garnet overgrowths that are elevated in Ca and depleted in Mn, Y and Sc, and CO₂-rich fluid inclusions that have reequilibrated to higher density (Th = 2-18 °C). Rim compositions of porphyroblasts yield P-T estimates of 5-6 kbar and 550-600 °C. The elevated Ca content of the overgrowths along with the presence of Ky in the matrix suggests that the reaction $An = Ky + Grs + Qtz$ may have been active during the overprinting metamorphism.

. The increase in pressure recorded in the granite aureoles in the Manhattan Prong is inconsistent with the results of P-T studies of the Rowe-Hawley belt, approximately 20 km to the east across Cameron's Line. This suggests that these two terranes may have been separated in the Devonian.

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Introduction

The Manhattan Prong, southeastern New York, is a sequence of Paleozoic metasedimentary rocks that experienced their dominant deformation and metamorphism during the Taconic Orogeny (~465 Ma; Sutter *et al.*, 1985), although later events are also recognized (Brock 1993). Several models have been proposed to describe the tectonic evolution of this region. In order to test these models and better constrain the pressure-temperature conditions associated with the tectonic evolution of the Manhattan Prong, data obtained from mineralogical thermobarometers and fluid inclusion studies were used. Combining these two types of complimentary information has proven to be useful for not only constraining peak metamorphic conditions but also for providing constraints on conditions during uplift (Hames *et al.*, 1989; Winslow *et al.*, 1994). To provide insight into the mechanisms that modify garnet zoning and cause fluid inclusions to reequilibrate during multiple metamorphic events, high resolution X-ray images of major and trace elements in garnets were collected and a detailed textural analysis of fluid inclusions was conducted.

The western Manhattan Prong shows petrologic evidence of having undergone loading shortly after peak Taconic metamorphism (Waldron, 1986). High-pressure contact metamorphism associated with the intrusion of the Cortlandt Complex occurred at ~435 Ma (Ratcliffe *et al.*, 1983) and is suggested to have resulted from the emplacement of a west-directed thrust slab upon the region just prior to intrusion (Waldron, 1986). This model is unusual in that typically metamorphic belts experience unloading following peak metamorphism, not additional loading. Pressure-temperature information from the contact aureoles of the Croton Falls and Peach Lake mafic complexes, in the eastern Manhattan Prong, provide an opportunity to test this model.

Approximately 20 kilometers east of the study area, in southwestern Connecticut, Hames *et al.* (1989) proposed a model for the metamorphic evolution of the Rowe-Hawley belt based on thermobarometry, fluid inclusions and thermochronology which calls for rapid uplift (~1.4 mm/yr; R. Tracy, 1997 personal comm.) following peak Acadian metamorphism at ~385 Ma (Sutter and Hatch, 1985). Constraints on uplift in the Manhattan Prong during this time can be obtained by comparing pressure estimates from regionally metamorphosed rocks with pressure estimates of contact metamorphism

associated with numerous, post-orogenic, ~350 million year old granites (Brock and Brock, 1985) which intrude the Manhattan Schist in the northeastern Manhattan Prong.

Geologic Setting and Tectonic Models

The Manhattan Prong, located in southeastern New York, is a geologic terrane that is bounded to the east by Cameron's Line, to the north by the Precambrian gneisses of the Hudson Highlands, and to the west by the Hudson River (Fig. 1).

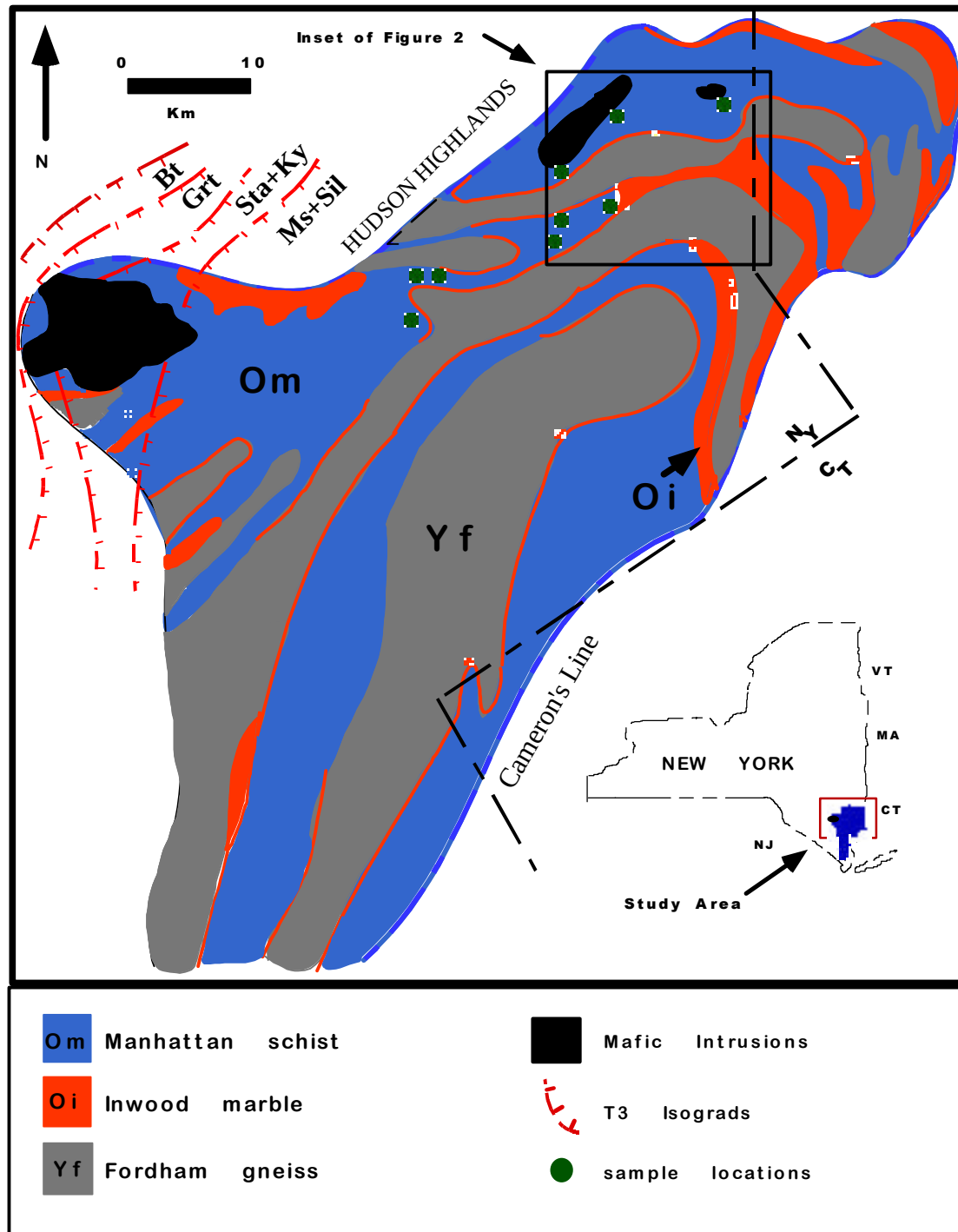


Figure 1. Generalized geologic map of the Manhattan Prong after Fisher *et al.*, 1970.

The major stratigraphic units in this area include the Proterozoic Fordham Gneiss and the overlying Cambro-Ordovician Inwood Marble and Ordovician Manhattan Schist. Portions of the Manhattan Schist are considered to be allochthonous (Hall, 1968) and probably share a similar history with the Taconic allochthons of upper New York State which were

emplaced early in the Taconic orogeny (Zen, 1967). NNE-trending metamorphic isograds in the Manhattan Schist reflect a prograde sequence, denoted as the T-3 domain by Sutter et al. (1985), ranging from biotite grade near the Hudson River to sillimanite+K-feldspar grade near the Connecticut border.

P-T conditions across the T-3 domain in Dutchess County, NY have been well documented by Whitney et al. (1996), who reported that metamorphic conditions ranged from a maximum of 475 °C and ~3-4 kbar in the garnet zone to greater than 720 °C and ~5-6 kbar in the sillimanite-k-feldspar zone. Similar results were obtained by Waldron (1986) who estimated metamorphic conditions varied from 450-475 °C and 3.5-4 kbar (garnet zone) to 630 °C and 7 kbar (sillimanite+muscovite zone) across the T-3 domain near the Cortlandt Complex. The Cortlandt Complex is a mafic, composite pluton that intrudes the Manhattan Schist across the T-3 isograds and has been dated between 430 and 440 Ma (Dallmeyer, 1975; Bender, 1980; Ratcliffe *et al.*, 1983). In a detailed study of the metamorphic conditions associated with the intrusion of the Cortlandt Complex, Waldron (1986) reported pressure estimates of 7-8 kbar for contact metamorphism. These estimates were 2 to 3 kbars higher than pressure estimates from the regional assemblage. To explain this discrepancy, Waldron (1986) proposed a model in which the regional pressure gradient was increased by the emplacement of a ~10 km thick thrust sheet from the east upon the region between the time of peak regional metamorphism and intrusion. Two other mafic bodies, the Croton Falls Complex and the Peach Lake Complex, occur to the east and are similar in composition to the Cortlandt Complex but much smaller (Fig 2).

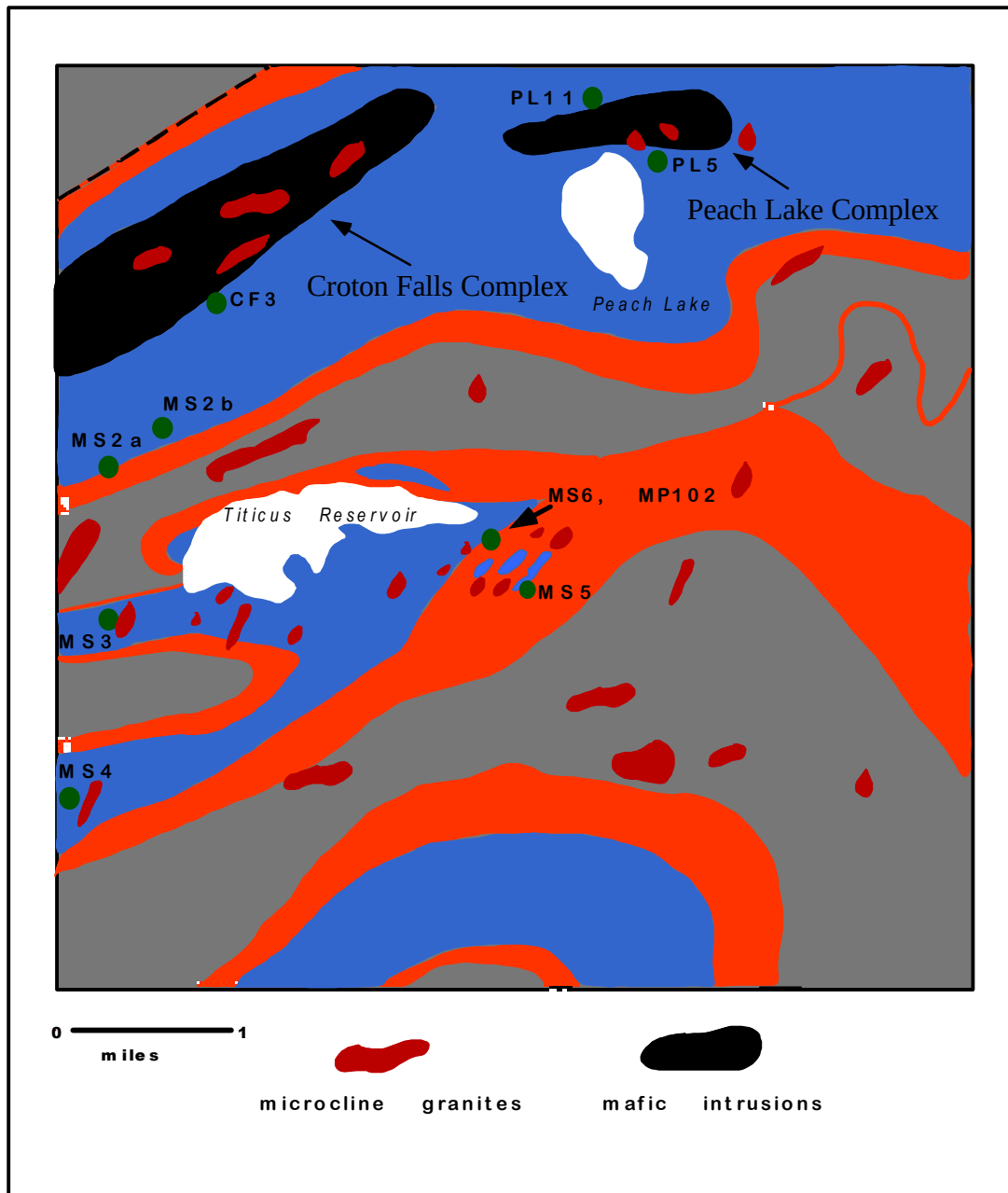


Figure 2. Generalized geologic map of the study area modified from Prucha *et al.*, (1968) showing the distribution of microcline granites, mafic intrusions and sample locations. Refer to figure 1 for legend.

Although little studied, these intrusions are thought to share the same genetic history as the Cortlandt Complex based on their proximity, mineralogy, and structural setting (Ratcliffe, 1970).

Prucha (1968) mapped the distribution of small granitic intrusions in the northeastern Manhattan Prong. These intrusions are commonly lenticular and have a

roughly north-northeast orientation. Brock et al. (1985) reported Rb/Sr ages of ~350 Ma for several of these plutons and were the first to recognize the effects that intrusion of the ~350 Ma granites and associated shearing had on the regional metamorphic grade in the eastern Manhattan Prong. Within north-northeasterly trending shear zones, regional upper-amphibolite facies assemblages have been retrograded to upper-greenschist to middle-amphibolite facies based on the disappearance of K-feldspar and sillimanite and the appearance of staurolite, kyanite and muscovite. P-T estimates of >4 kilobars and ~550 C were reported based on the absence of andalusite in these assemblages and limited garnet-biotite thermometry (Brock, 1993). Based on microstructural evidence from areas of intrusion and K/Ar ages of 358 ± 7 Ma from recrystallized muscovite, Brock (1993) suggested that intrusions were syntectonic with post-Acadian dextral strike-slip faulting.

Although widespread evidence for Acadian metamorphism is recognized throughout southwestern New England (Hames et al., 1989, 1991; Miller and Tracy, 1991), only subtle overprinting effects on Taconian rocks have been reported to the west near Cameron's Line, the generally recognized western limit of Acadian metamorphism (Hames et al., 1991). The effects of Acadian metamorphism have not been reported west of this area, although Acadian folding is present in Dutchess County, directly north of the study area (Ratcliffe et al., 1985), indicating that this region was involved in Acadian deformation. Therefore tectonic models of the Acadian Orogeny proposed for rocks of southwestern New England may have bearing on the tectonic evolution of the northeastern Manhattan Prong. On the basis of mineral equilibria, Hames *et al.* (1989) reported peak Acadian metamorphic conditions of 575 °C and 8.2 kbar from the Devonian Rowe-Hawley belt of western Connecticut. H₂O- and CO₂-rich fluid inclusions from matrix quartz were used along with published ⁴⁰Ar/³⁹Ar data from hornblende and muscovite (Dietsch and Sutter, 1987) to constrain a tectonic model in which rapid (~1.4 mm/yr), nearly isothermal, decompression of the region was followed by slower (<0.3 mm/yr), nearly isobaric cooling (Hames et al, 1989).

Analytical Techniques

Major and trace element abundances were determined using a CAMECA SX-50 fully automated electron microprobe at Virginia Tech. Beam conditions for quantitative

analysis of major elements were 15 keV accelerating potential with a current of 20 nA. Beam conditions for quantitative analysis of trace elements were 15 keV accelerating potential with a current of 70 nA. Beam conditions during WDS X-ray mapping of major elements were 25 keV and 50 nA and 25 keV and 700 nA during WDS X-ray mapping of trace elements. Data were reduced using the method of Pouchou and Pichoir (1985) and mineral formulae were calculated based on the number of oxygens per anhydrous formula unit. Errors in trace element analyses were calculated using the CAMECA software and reported as 2-sigma error bars on microprobe traverses. The results of microprobe analyses are given in appendix I.

The temperatures of phase changes of fluid inclusions were obtained using a Linkam THMS 600 heating and cooling stage in the Fluids Research Laboratory at Virginia Tech. The stage was mounted on a Leitz Orthoplan microscope equipped with a 100x objective and 10x oculars. Inclusions ranged from 2-15 microns and thermal cycling was used to obtain T_h owing to the small size. A heating rate of 1°C/minute was used in the vicinity of phase transitions. The stage was calibrated at -56.6 °C, 0.0 °C, and 374.1 °C using synthetic fluid inclusions (Bodnar and Sterner, 1987). The accuracy and precision of phase transitions reported here are ± 0.1 °C. Results of freezing measurements suggested the presence of components other than CO₂ in the inclusions, and these were identified by Raman Spectroscopy. Raman analyses were obtained with a Dilor X-Y microprobe using the 514 nm line of a 5-watt Ar laser as the excitation source. The Raman probe is located in the Vibrational Spectroscopy Laboratory at Virginia Tech. The densities of CO₂ inclusions were determined from the measured homogenization temperature using the data of Thiery *et al.* (1994). Isochores corresponding to these densities were calculated using the modified Redlich-Kwong equation of Holloway (1981). The results of microthermometric measurements are given in appendix II.

Sample Description

Samples of Manhattan Schist were collected from the Peach Lake and Croton Falls quadrangles, northeastern Manhattan Prong. This area is approximately 25 km east of the sillimanite-muscovite isograd and many samples of regionally metamorphosed pelite from here contain K-feldspar in addition to muscovite and sillimanite, indicating the proximity

of a sillimanite-K-feldspar isograd, the exact location of which has not been determined. The most common mineral assemblage found is quartz-plagioclase-biotite-sillimanite-garnet $\pm$ K-feldspar $\pm$ muscovite with ilmenite, hematite, apatite, zircon, and monazite occurring as accessory phases. Fibrolite, biotite and muscovite (when present) define the dominant foliation in these samples.

Samples of the Manhattan Schist were also collected adjacent to the Peach Lake and Croton Falls mafic complexes as well as near or within ~350 Ma shear zones that have been syntectonically intruded by small, granitic plutons (Brock, 1993). The assemblage from within the contact aureole of the Peach Lake Complex consists of quartz-plagioclase-biotite-sillimanite-garnet with porphyroblasts of kyanite and staurolite growing across foliation. Samples collected within the contact aureole of the Croton Falls Complex contain the assemblage plagioclase-quartz-biotite-sillimanite-garnet with spinel occurring both in the matrix and as inclusions in garnet. Adjacent to the granitic intrusions the assemblage consists of quartz-plagioclase-biotite-sillimanite-garnet-muscovite-K-feldspar with rare kyanite growing across foliation. Where shearing is strongest the assemblage consists of only quartz-plagioclase-biotite-muscovite-garnet, and biotite and muscovite comprise the foliation.

Mineral Chemistry and Compositional Zoning in Garnet

The selection of mineral compositions to use in thermobarometric calculations can greatly influence estimates of pressure and temperature. Assessing the equilibrium state of an assemblage is difficult at best, especially in polymetamorphic terranes. It can be expected that the chemistry of those minerals with higher diffusion rates (e.g. biotite) may completely reequilibrate during remetamorphism whereas minerals with slower rates (e.g. garnet) may retain some degree of their original chemistry. Therefore a rock from a polymetamorphic terrane may contain a disequilibrium assemblage and the choice of which mineral compositions to use for thermobarometric calculations can be difficult. X-ray imaging of compositionally zoned phases can aid in the selection of mineral pairs used for thermobarometric calculations and becomes a necessary requirement for obtaining pressure and temperature estimates in polymetamorphic terranes. Several garnets from each thin section were mapped for Fe, Mg, Mn, and Ca. Two garnets, one from a

regionally metamorphosed sample and one from a sample collected adjacent to a granite intrusion, were mapped for P, Sc, Y, and Cr in addition to the major elements.

Although garnets from all samples are almandine-rich [$X_{\text{alm}} = 0.68 - 0.80$], major and trace element zoning varies depending on the tectonic history of the samples. X-ray images show that garnets from regional samples are homogenous with respect to Fe, Mg, Ca, and Mn, but zoned with respect to the trace elements Y and P (Figs. 3, 4).

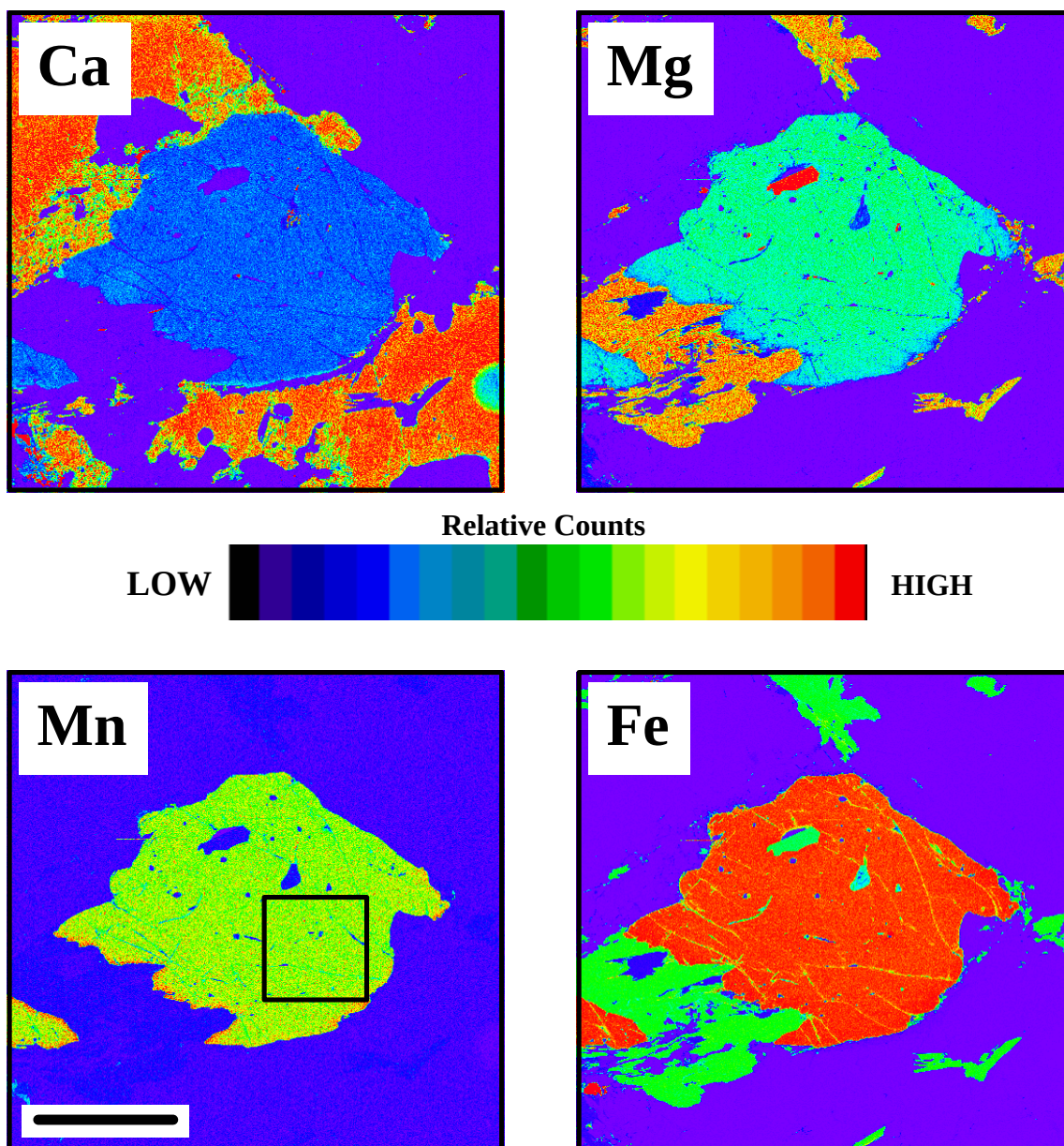


Figure 3. X-Ray maps of a regionally metamorphosed garnet from sample MS2AG2 showing the distribution of major elements. Box represents area imaged in figure 4 . Scale bar represents 1 mm.

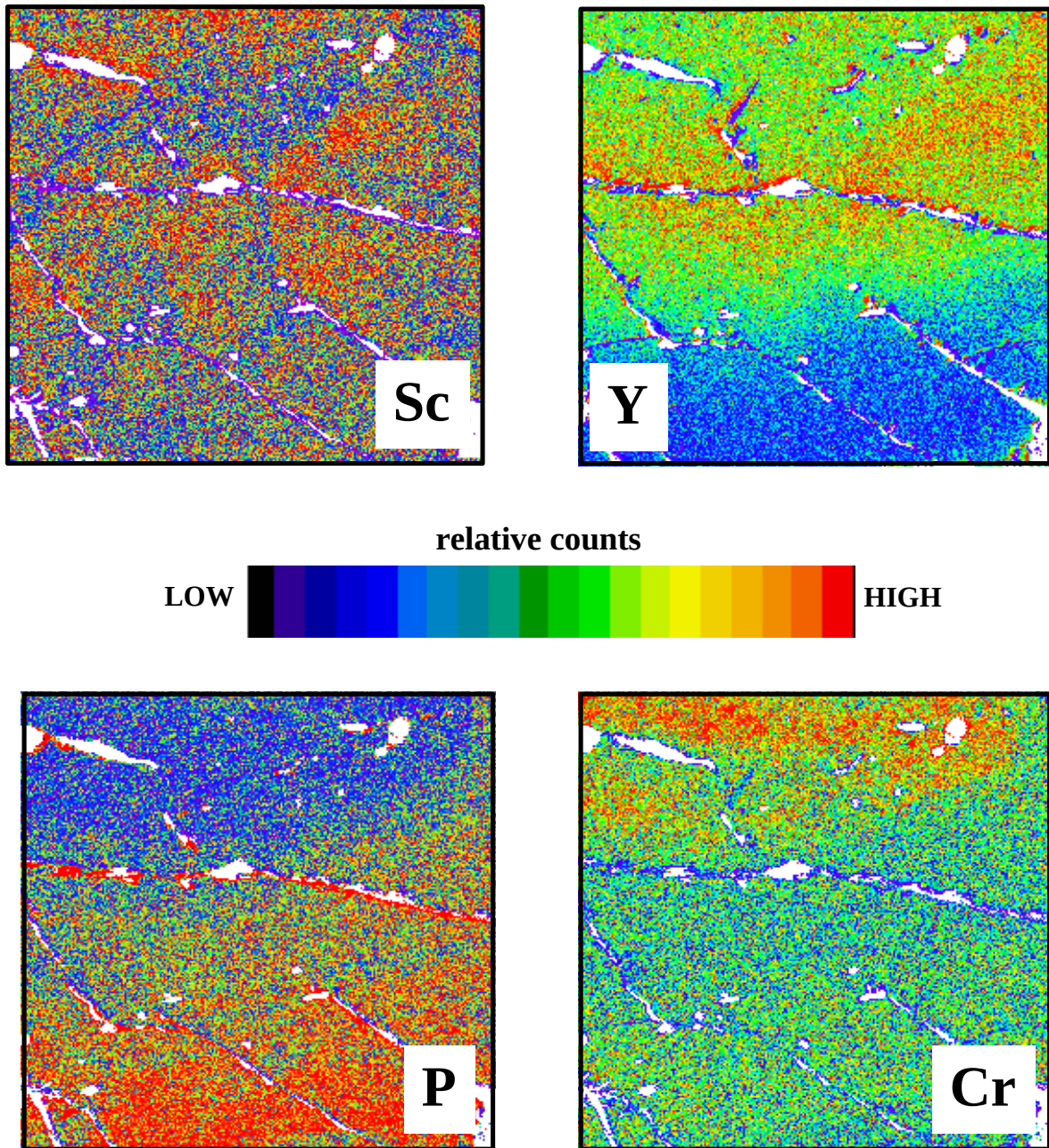


Figure 4. X-Ray maps of regionally metamorphosed garnet from sample MS2AG2 showing the distribution of trace elements. Image width is approximately 500 μm . Refer to figure3 for location of image.

The results of microprobe analyses collected along a traverse from rim to core of this garnet are presented in figure 5.

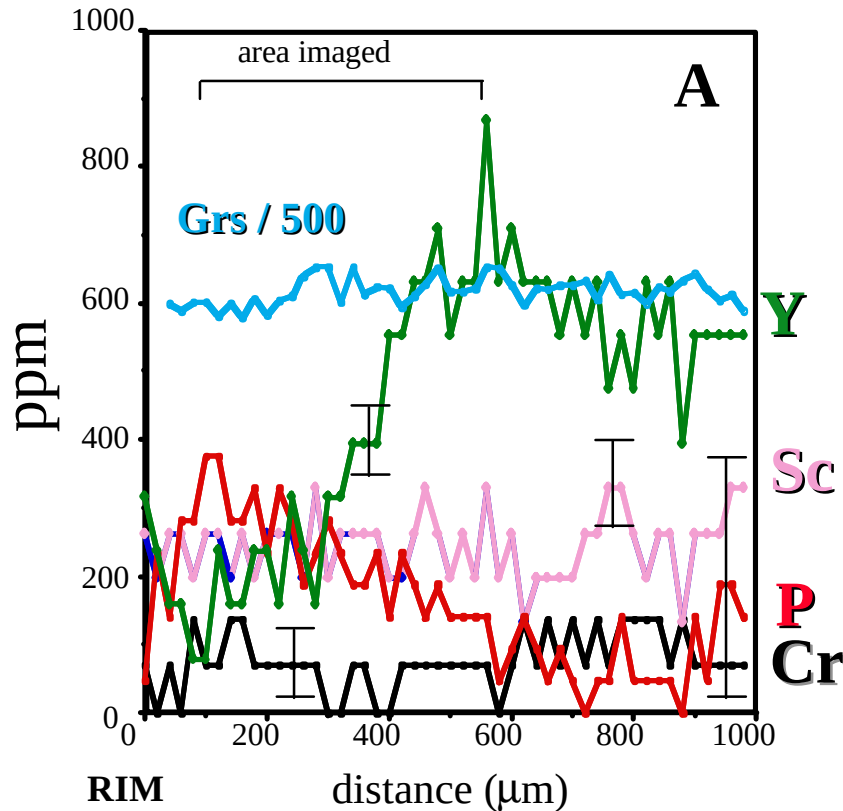


Figure 5. Microprobe analyses of trace elements in garnet collected along a traverse from rim to core across area imaged in figure 4. Grossular content is also plotted to show contrast between the major and trace element zoning in this garnet.

The results show that the concentrations of both Y and P vary from rim to core. Y sharply decreases from ~300 ppm at the rim to ~75 ppm before gradually increasing to ~900 ppm in the core. P sharply increases from <50 ppm at the rim to ~390 ppm before gradually decreasing to ~100 ppm in the core. Matrix biotite from these samples is unzoned with an average Fe/(Fe+Mg) of 0.60. Biotite inclusions in garnets have an average Fe/(Fe+Mg) of 0.50. Plagioclase is unzoned except adjacent to garnet where it shows normal zoning with anorthite enriched in the cores relative to the rim.

X-ray images show that garnets from samples near granite intrusions are fairly homogenous with respect to Fe and Mg but show increases in Ca and decreases in Mn near the rim (Fig. 6).

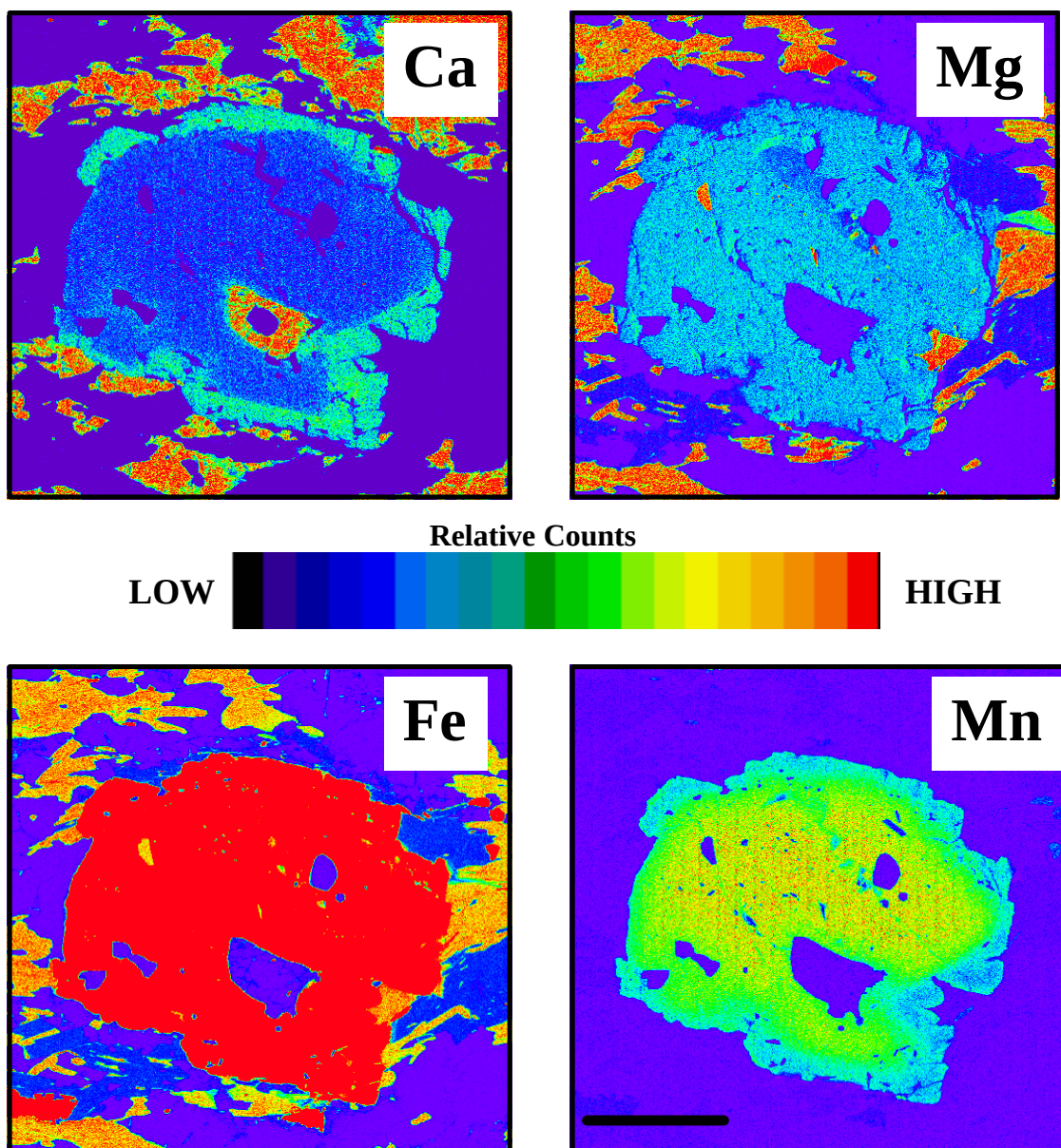


Figure 6. X-Ray maps of contact metamorphosed garnet from sample MS3BG1 showing the distribution of major elements. Scale bar represents 0.5 mm.

In several garnets these chemical discontinuities can be correlated with an observed textural break near the rim of the garnet (Fig 7).

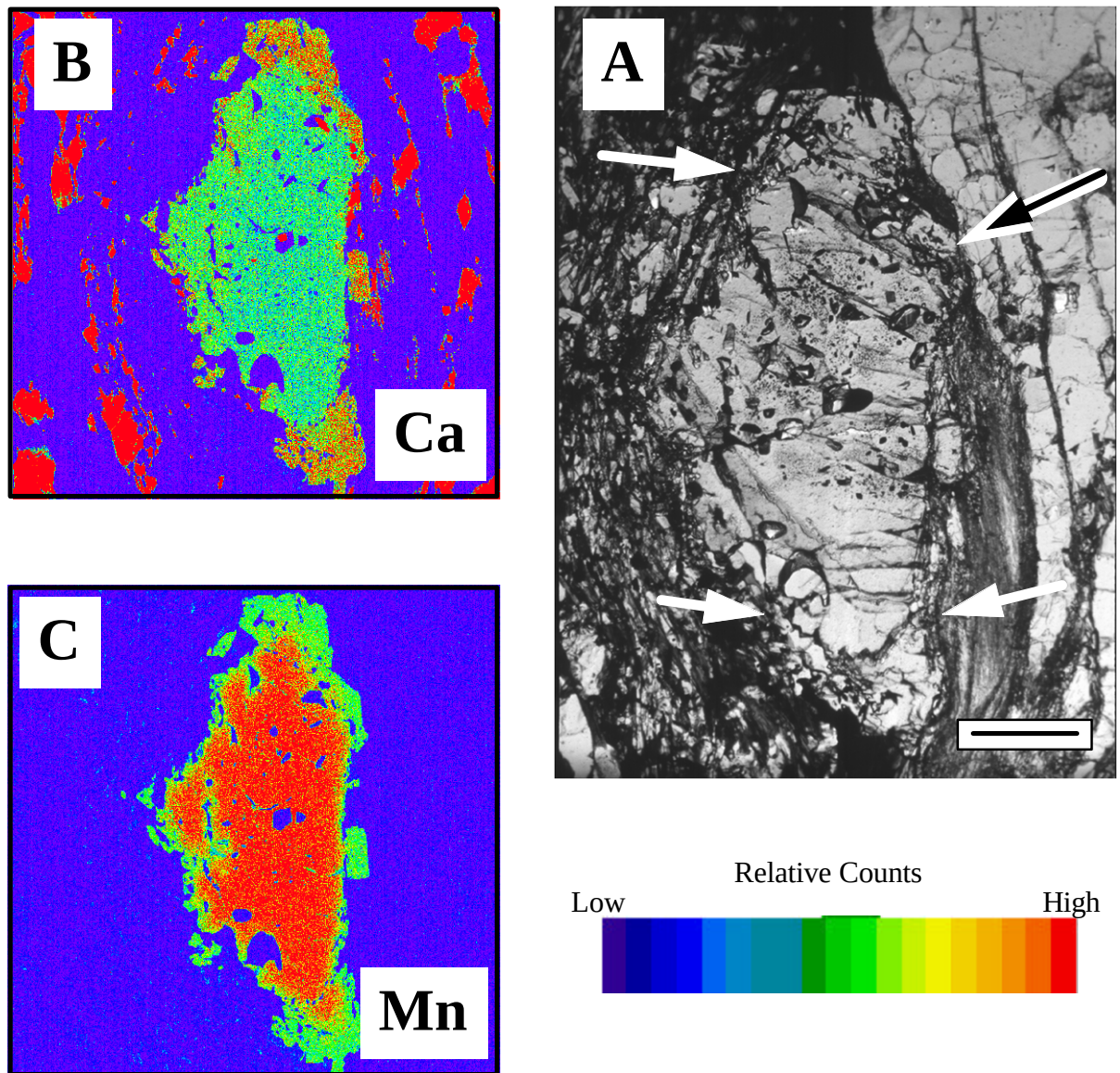


Figure 7. A. Photomicrograph of garnet porphyroblast that shows textural overgrowths. B. and C. are X-ray maps of the same garnet showing enrichment of Ca and depletion of Mn in the overgrowths. Scale bar in A represents 1mm.

The discontinuity can also be observed in trace element zoning of Y and Sc (Fig. 8).

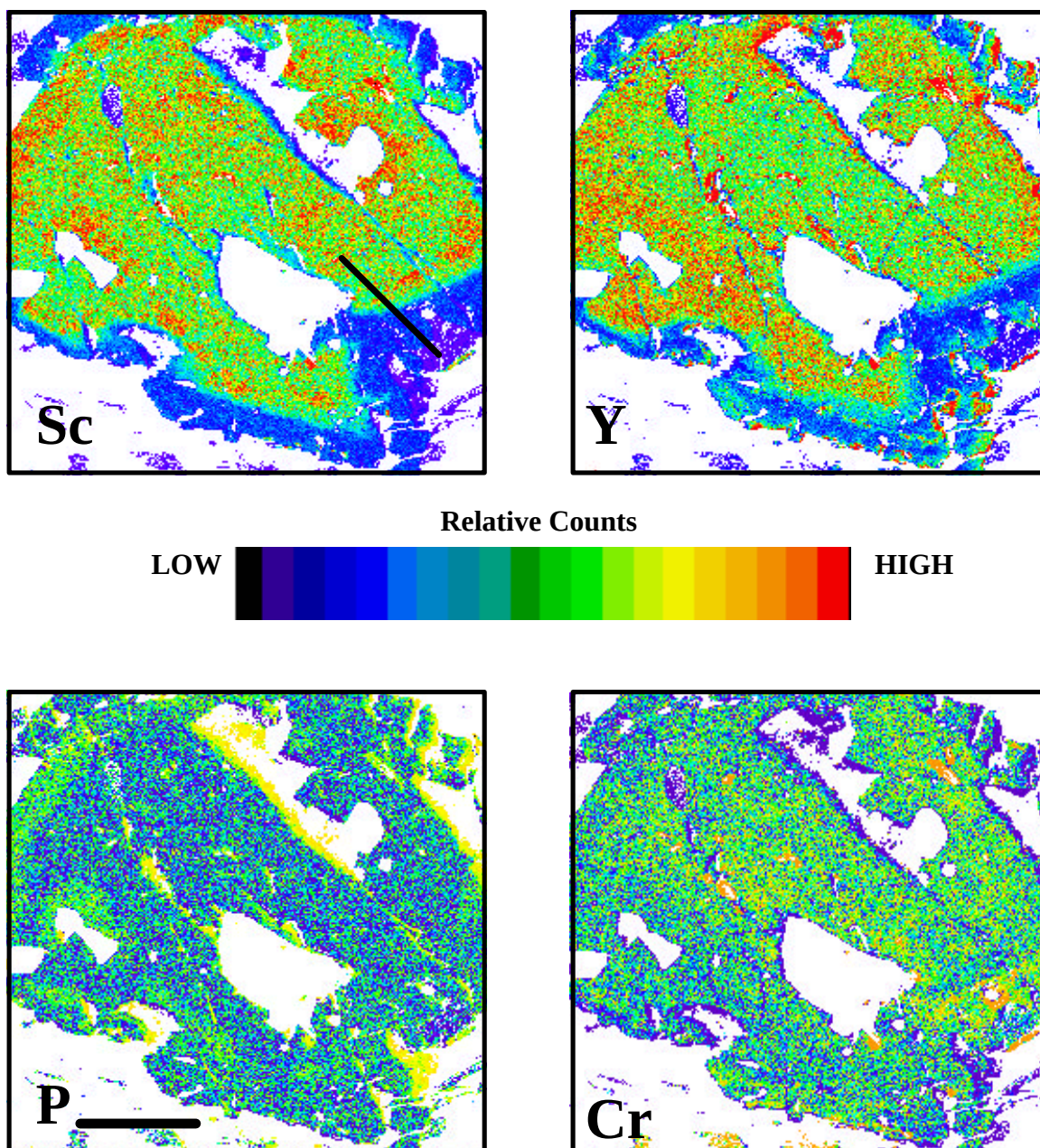


Figure 8. X-Ray maps of contact metamorphosed garnet from sample MS3BG2 showing the distribution of trace elements. Black line in Sc images corresponds to location of traverse shown in figure 9 . Scale bar represents 0.5 mm.

The results of microprobe analyses collected along a traverse across the discontinuity in a garnet are presented in figure 9.

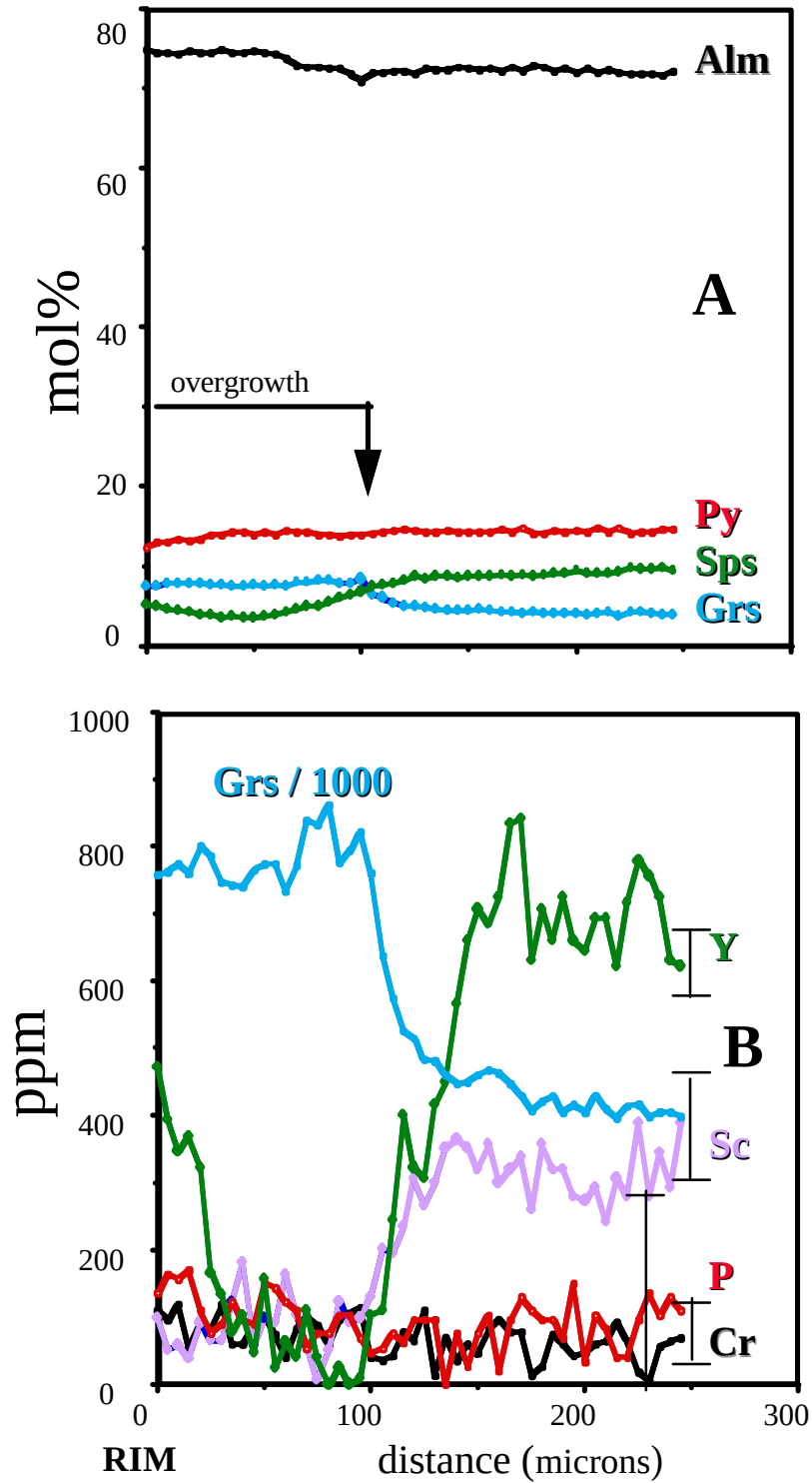


Figure 9. Microprobe analyses collected along a traverse across the discontinuity in a garnet (MS3BG2) collected next to a granite intrusion. Area of traverse is shown in figure 8. Black arrow in A points to strong inflection in grossular and spessartine components which corresponds to a textural break. Grossular content has also been plotted in B to show contrast between major and trace element zoning in this garnet.

The results show that X_{gr} increases from ~4 mol% in the interior to ~8 mol% in the rim while X_{sp} decreases from ~10 mol% to ~4 mol%. Y decreases sharply from ~850 ppm to <50 ppm across the discontinuity and Sc decreases sharply from ~450 ppm to ~100 ppm. Matrix biotite from these samples is unzoned with an average Fe/(Fe+Mg) of 0.60. Biotite inclusions in garnets have an average Fe/(Fe+Mg) of 0.48. Plagioclase is unzoned except adjacent to garnet where it shows normal zoning. Garnets from samples that show a high degree of shearing (MP102) overgrow foliation and are homogenous with respect to all elements analyzed.

Garnets from samples collected adjacent to the Peach Lake mafic intrusion are slightly zoned with respect to Ca and Mn but garnets from samples collected adjacent to the Croton Falls intrusion are completely homogenous with respect to major elements (Fig 10).

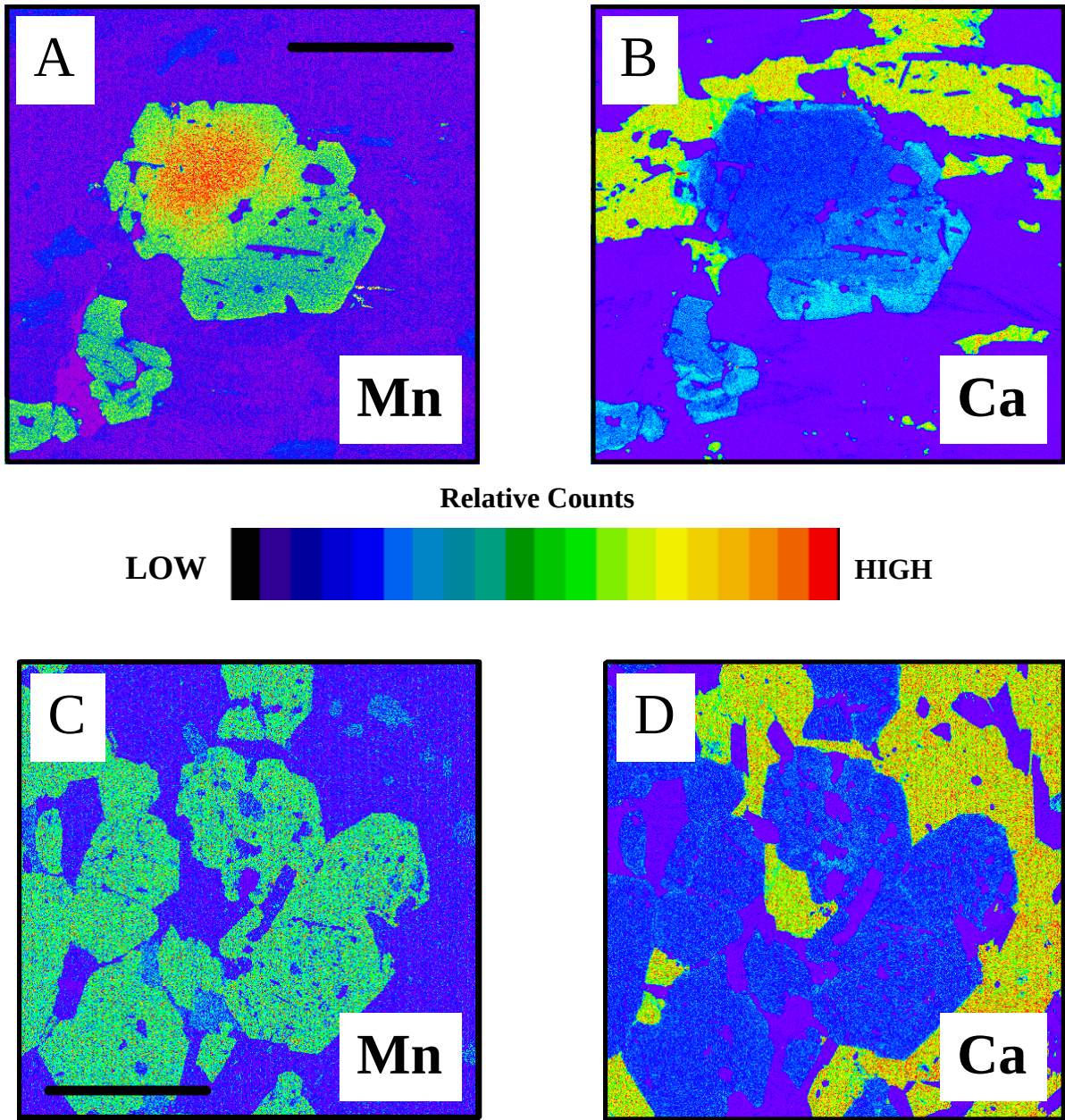


Figure 10. X-Ray maps showing distribution of Ca and Mn in garnet from aureoles of mafic intrusions. Garnet shown in A and B is from the aureole of the Peach Lake Complex. Note slight enrichment of Ca and depletion of Mn near rim. Garnet shown in C and D is from the aureole of the Croton Falls Complex. Distribution of Ca and Mn in this garnet is homogenous. X-ray maps of Fe and Mg (not shown) for both groups of garnet show no zoning. Scale bar represents approximately 1mm.

Thermobarometry

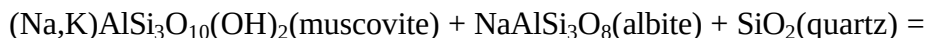
The metamorphic conditions under which mineral assemblages of the Manhattan Schist equilibrated were calculated using calibrated mineral reactions and ion-exchange equilibria. Temperatures were calculated using the garnet-biotite exchange equilibrium of Ferry and Spear (1978) with the Berman (1990) garnet activity model. Pressures were calculated with the GASP geobarometer of Koziol and Newton (1988), using the almandine and pyrope activity models of Hodges and Crowley (1985). Table 1 presents the results of thermobarometric calculations from both regionally metamorphosed samples and samples modified by contact metamorphism. Each value represents an average of 2-3 calculations from a thin section.

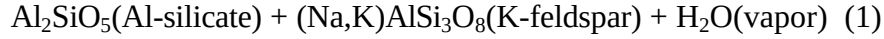
Table 1 Temperature (°C) and Pressure (kbar) Estimates

<u>sample</u>	<u>location</u>	<u>T(°C)</u>	<u>P(kbar)</u>
Regional			
MS2A-G2	rim+matrix	760	4.0
MS2A-G2	core+inclusions	680	no plagioclase
MS2A-G6	rim+matrix	720	4.3
MP9	rim+matrix	735	5.7
Contact			
MS3B-G2	rim+matrix	600	5.5
MS3B-G2	core+inclusions	680	3.8
MS5	rim+matrix	575	5.5
MS4	rim+matrix	575	6.0
CF3	rim+matrix	700	4.0
PL11	rim+matrix	575	4.2

Regional Assemblages

Lack of zoning in all phases (except biotite and plagioclase grains in contact with garnets) from regionally metamorphosed samples is a good indicator that the regional assemblage may approximate equilibrium conditions. An estimate of the P-T conditions for the metamorphism of these samples can be obtained from the reaction:





This reaction and the results of temperature and pressure determinations from regional samples are plotted in figure 11.

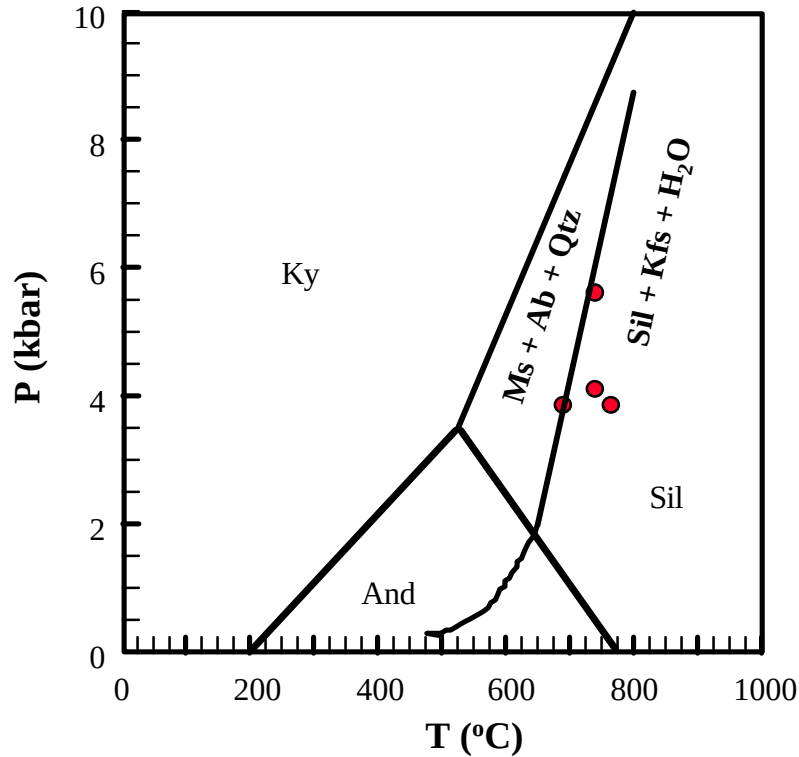
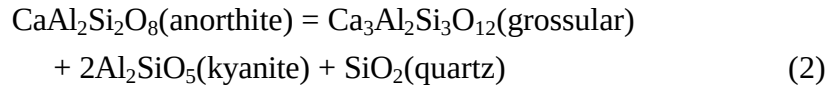


Figure 11 . Pressure-temperature plot of calculated thermobarometric results from regionally metamorphosed samples. Also shown is the Al_2SiO_5 triple point of Holdaway (1971) and the muscovite + quartz stability curve of Kerrick (1972).

Contact Assemblages

Due to the extreme disequilibrium nature of these assemblages, compositional maps or profiles were collected from all phases used in thermobarometric calculations. Estimates of overprinting metamorphic conditions were obtained by pairing garnet rim compositions with matrix biotite and plagioclase rim compositions (where normal zoning is apparent). Wherever possible, garnet core compositions were matched with biotite and plagioclase inclusions in the cores of garnets in an attempt to obtain estimates of regional metamorphic conditions (shown as green square in figure 12)

Garnet overgrowths with elevated calcium content, along with the presence of kyanite in samples collected adjacent to granite intrusions, suggest the following reaction may have been operative during contact metamorphism:



A similar mineral assemblage is also found in samples collected adjacent to the Peach Lake intrusion. Garnet rims from these samples show slight enrichment of calcium and depletion of manganese (Fig. 10), and staurolite and kyanite appear in the matrix (in addition to garnet-sillimanite-plagioclase-biotite-quartz).

Samples collected next to the Croton Falls Complex contain plagioclase-biotite-sillimanite-quartz-garnet-spinel along with magnetite. Alteration of this assemblage is evidenced in some samples by staurolite, chlorite and white mica replacing much of the original assemblage (Brock & Brock, 1981). Spinel and sillimanite are not found in altered samples suggesting that they were reactants in the alteration process. P-T estimates from garnet-biotite thermometry and garnet-plagioclase barometry for the aureoles of both the Peach Lake and Croton Falls Complexes, as well as the results from samples collected adjacent to granite intrusions, are shown in figure 12.

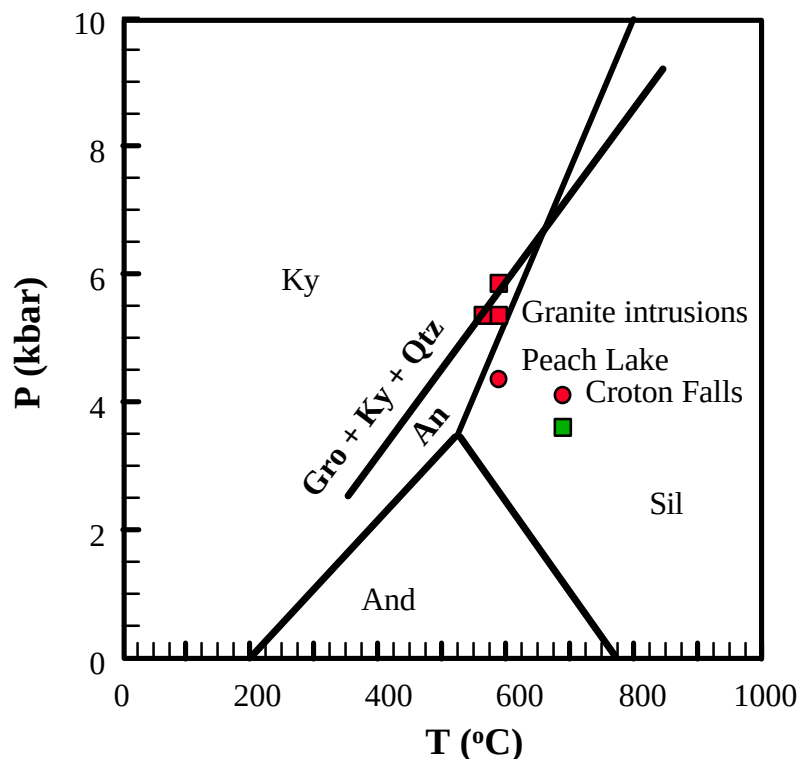


Figure 12 . Pressure-temperature plot of calculated thermobarometric results from contact metamorphosed samples overlain on the Al_2SiO_5 triple point of Holdaway (1971). Results from samples collected adjacent to the mafic intrusions are shown as red circles. Results from samples collected adjacent to granite intrusions are shown as red squares. Also shown are the results from mineral inclusion thermobarometry from samples collected adjacent to granite intrusions (green square). GASP reaction plotted using the $\text{K}_{\text{eq}} = 350$ isopleth of Koziol and Newton (1988) calculated from average activities of grossular and plagioclase from samples collected adjacent to granite intrusions.

Fluid Inclusions

Fluid inclusions from the Manhattan Prong record evidence for the multiple tectonothermal events inferred from garnet zoning and mineralogical geothermobarometers. Fluid inclusion assemblages (FIAs; Goldstein and Reynolds, 1994) were characterized on the basis of their location within a particular mineral, homogenization temperature of the inclusions, and the inclusion shape. Constraints on the timing of different FIAs were obtained by relating textural observations to the known metamorphic reaction history. All of the inclusions have similar compositions, and FIAs were designated as A-E based on their occurrence in minerals. Relative timing of

entrapment of each FIA and corresponding petrologic features are shown in the following table:

Table 2

<u>Time</u>	<u>Petrology</u>	<u>Mineral growth</u>	<u>Fluid Inclusions</u>
~465 Ma	Taconic regional metamorphism	Gt cores	CO ₂ -N ₂ (A)
~435 Ma	Intrusion of the Cortlandt, Croton Falls and Peach Lake Complexes		
~350 Ma	Intrusion of granites and shearing	Gt overgrowths kyanite	CO ₂ -N ₂ (B,C,D,E)

FIA-A: CO₂-rich Fluid Inclusions in Garnet Cores

Abundant, negative crystal-shaped fluid inclusions occur in clusters near the cores of garnets from regionally metamorphosed samples (Fig. 13).

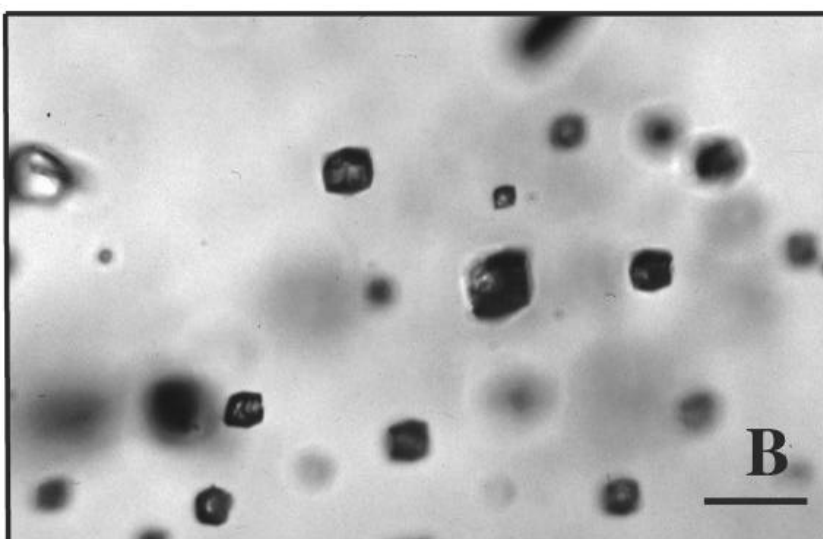
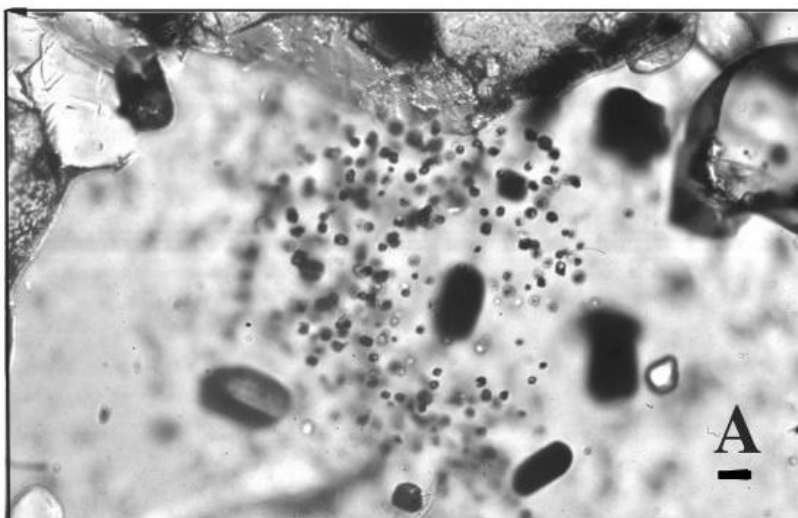


Figure 13. CO₂-rich fluid inclusions in regionally metamorphosed garnet (FIA-A). Scale bar represents 10 μ m.

These inclusions range in size from $<1\mu\text{m}$ to approximately $10\mu\text{m}$. Melting temperatures range from $-56.6\text{ }^{\circ}\text{C}$ to $-61.5\text{ }^{\circ}\text{C}$ (see appendix). The freezing-point depression is due to the presence of a small amount of N_2 based on Raman spectroscopy (Fig. 14).

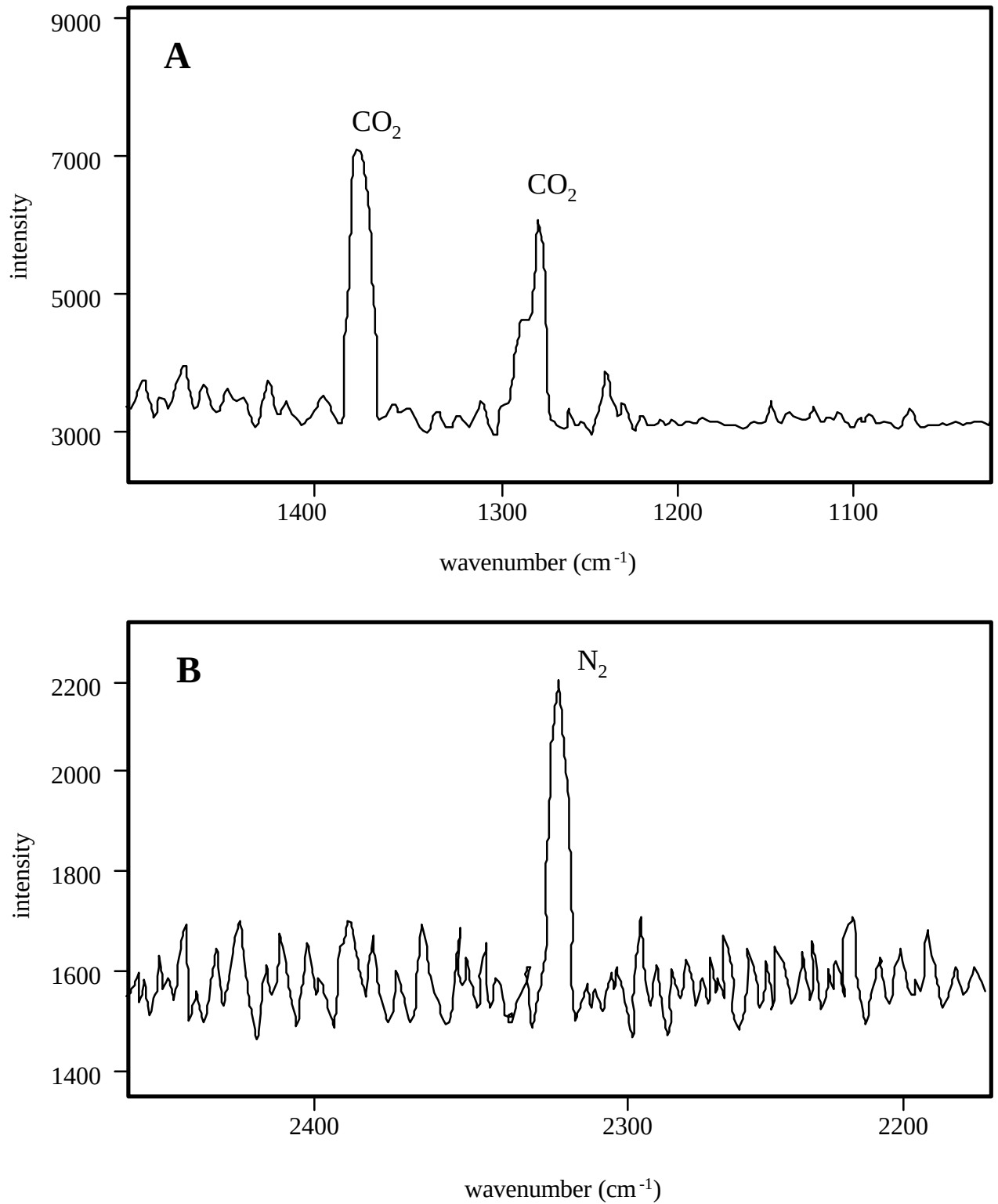


Figure 14. Raman spectra of Stage A fluid inclusions. Spectra A shows CO_2 peak, Spectra B shows N_2 peak.

According to calculations by some workers, a 2°C depression may correspond to as much

as 10 to 15 mole % N₂ (Burruss, 1981; Touret, 1987). No H₂O was detected optically or by Raman spectroscopy and clathrate melting was not observed. The inclusions often contain one or more solid phases that have been identified either optically or by electron microprobe and include hematite, ilmenite, apatite, biotite, and muscovite. No systematic pattern to the occurrence of solid phases in these inclusions is apparent and they are considered to be trapped phases. Upon heating, these inclusions homogenize to liquid at temperatures that range from approximately 10 °C to 25 °C (Fig. 15).

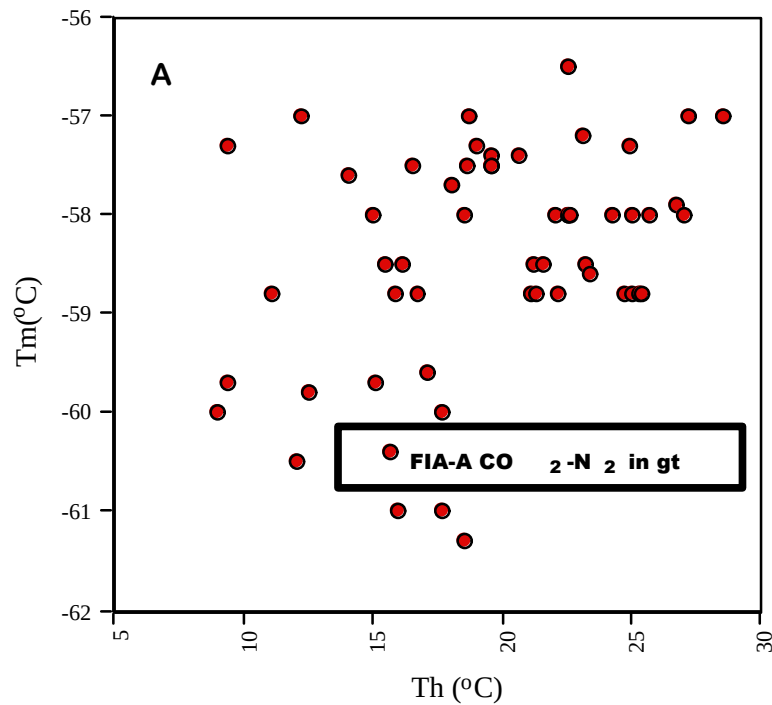


Figure 15. Melting temperature (T_m) vs. homogenization temperature (T_h) of CO₂-rich fluid inclusions from regionally metamorphosed garnet cores (Stage A).

FIA-B: CO₂-rich, Reequilibrated Fluid Inclusions in Garnet Cores

In samples collected adjacent to granite intrusions some negative crystal-shaped fluid inclusions in cores of garnets show a spiky, star-shaped texture (Fig. 16).

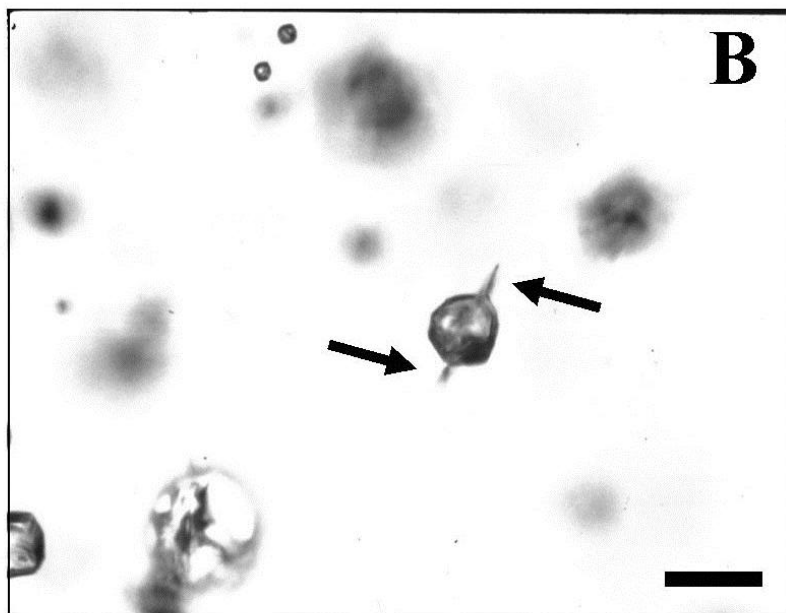
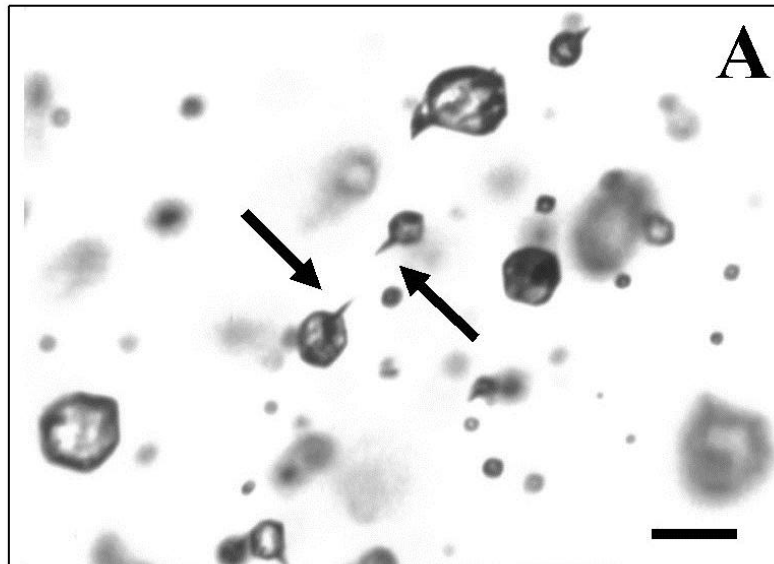


Figure 16. Negative crystal-shaped CO₂-rich fluid inclusions displaying fractures at their edges (FIA-B). Fluid inclusions displaying fractures homogenize to liquid at lower temperatures than pristine inclusions. Note in A that both large and small pristine inclusions coexist with fractured inclusions. Scale bar represents 10 μ m.

These inclusions are similar in composition to FIA-A inclusions with melting temperatures that range from -56.6 °C to -58.8 °C. Upon heating, however, these inclusions homogenize to liquid over a much wider range of temperatures, from approximately -0.5 °C to 18.6 °C (Fig 17).

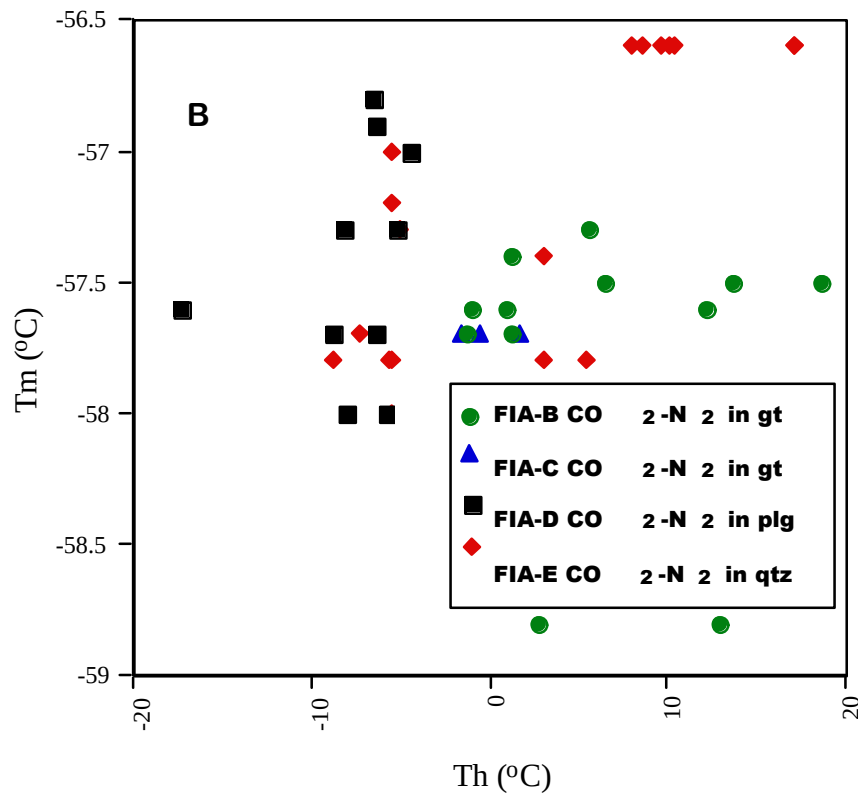


Figure 17. Melting temperature (T_m) vs. homogenization temperature (T_h) of CO₂-rich fluid inclusions from contact metamorphosed garnet and matrix plagioclase and quartz (Stage B).

FIA-C: CO₂-rich Fluid Inclusions in Garnet Rims

Small (3-10 µm), rounded inclusions occur along curved planes in the rim of garnet porphyroblasts (Fig. 18) from samples collected adjacent to granite intrusions.

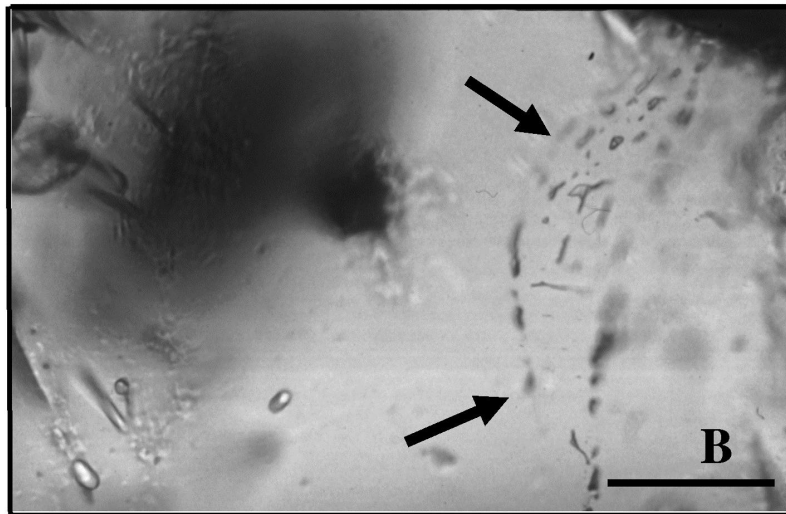
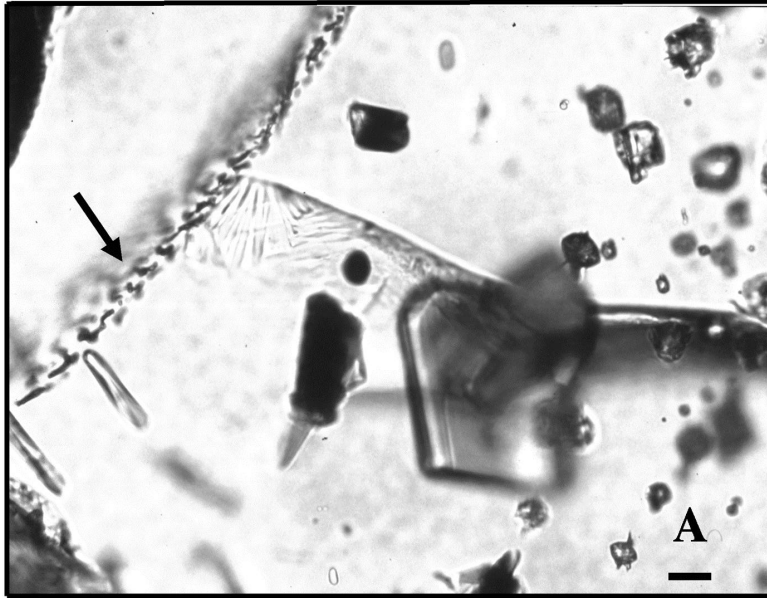


Figure 18. Black arrows point to CO₂-rich fluid inclusions that form along healed fracture planes near the rim of garnets that have been modified by contact metamorphism (FIA-C). Dark phases in A are biotite and ilmenite. Scale bar represents 10 μ m.

These inclusions contain a CO₂-rich fluid in addition to one or more solid phases, similar to inclusions in garnet cores. Melting occurs at approximately -57.7 °C and upon heating these inclusions homogenize to liquid between -0.5 °C and 1.7 °C (Fig 17). No water was detected optically and the formation of a clathrate was not observed.

FIA-D: CO₂-rich Fluid Inclusions in Matrix Plagioclase

Negative crystal-shaped inclusions containing a CO₂-rich fluid occur in linear arrays along twin planes in matrix plagioclase from samples collected adjacent to granite intrusions. Many inclusions have one or more unidentifiable solid phases within them. They range in size from 5-15µm and have a melting temperature of approximately -57.6 °C (Fig. 17). Upon heating these inclusions homogenize to a liquid at -3.5 °C to -8.8 °C.

FIA-E: CO₂-rich Fluid Inclusions in Matrix Quartz

Fluid inclusion assemblages in quartz consist of linear arrays of negative crystal-shaped inclusions which occur along curved planes and contain a CO₂-rich fluid. These inclusions melt at approximately -57.8 °C and homogenize to a liquid at -8.7 °C to 17.1 °C (Fig. 17).

Discussion

Garnet Zoning

The distribution of major and trace elements in garnets provides information about the processes active during and following garnet growth. This information is essential for accurate geothermobarometry, especially in polymetamorphic terranes. A comparison of the major and trace element zoning patterns from several garnets collected in this study reveals distinct differences. Garnets from regionally metamorphosed samples are fairly homogenous with respect to major elements Fe, Mg, Ca, and Mn. Garnets from high-grade terranes commonly lack major element zoning because the diffusion rate for many major elements is high and any original zoning developed during the growth of the garnets is erased (Tracy, 1982). However, zoning of Y and P is preserved in these garnets. There is evidence that trace element zoning is not modified by diffusive processes (Spear and Kohn, 1996), hence trace element zoning in this garnet may be interpreted as zoning that was developed during growth of the garnet. Two ways of producing trace element zoning in garnet were proposed by Hickmott et al, (1987). The first is through the introduction of a pulse of trace element-enriched fluids into the system during garnet growth and the second is through the breakdown of a refractory mineral enriched in trace elements. Similarly, Lanzirotti (1995) proposed that oscillatory Y zoning in a garnet from the Straits

Schist, Connecticut, reflects either the breakdown of Y-enriched phases, changes in the rate of garnet growth, or changes in the Y concentration of the matrix due to the breakdown and reprecipitation of the garnet. The trends of the zonation of Y and P in regionally metamorphosed garnets from the Manhattan Schist are relatively gradual suggesting that the mechanism that was responsible for them was active throughout the growth of the garnet. At this time, however, there are insufficient data to constrain the origin of the trace elements in garnets from the Manhattan Schist and the mechanisms responsible for trace element zoning can only be speculated.

Major and trace element zoning in garnets collected from the aureoles of granite intrusions reveal garnet overgrowths enriched in Ca and depleted in Mn, Sc and Y. The presence of garnet overgrowths only in samples collected adjacent to intrusions suggests that overgrowths were formed during contact metamorphism. The enrichment of Ca in garnet overgrowths may be related to reaction (2).

These observations are similar to those reported by Stowell *et al.* (1996) who proposed that episodic Ca-metasomatism related to plutonism was responsible for oscillatory zoning of both major elements and the trace elements Na, Y, Yb and Zr in garnets collected adjacent to dioritic intrusions in southeast Alaska. A strong negative correlation between Ca concentration and Y and Yb concentration was used as evidence that fluids involved in garnet growth were enriched in Ca and depleted in Y and Yb. An inverse relationship between Ca concentration and Y and Sc concentration within garnet overgrowths was observed in this study, but there is no other independent evidence to suggest that the compositional variations are related to fluid infiltration.

The trace element distribution in regionally metamorphosed garnets differs from the trace element distribution in the interior of remetamorphosed garnets. In regionally metamorphosed garnets Y and P show a gradual increase and decrease, respectively, towards the core, whereas in the interior of remetamorphosed garnets Y oscillates and P shows no variation. Assuming these two garnets initially had the same zoning patterns, this suggests that the distribution of some trace elements in the interior of remetamorphosed garnets may have been modified during the overprinting metamorphism. Alternatively, the differences in trace element zoning in these two groups of garnet may be original and might reflect minor differences in bulk composition.

The location of overgrowths on garnets from samples which show evidence of shear (Fig. 7) indicates that garnet growth during contact metamorphism was limited to pressure shadows. This supports the hypothesis offered by Brock (1993) that intrusion was syntectonic. Garnets from samples which show the highest amount of shear are completely homogenous with respect to major elements and strongly overgrow the biotite-muscovite foliation. These garnets appear to have grown late in the shearing/intrusive event. P-T estimates using these garnets and matrix biotite and plagioclase yield unrealistic values indicating that they are not an equilibrium assemblage.

Garnets from samples collected adjacent to the Croton Falls Complex are completely homogenous with respect to major elements and are texturally different from garnets in regionally metamorphosed samples. Lack of perturbations in major element zoning suggests that these garnets grew during contact metamorphism and experienced no subsequent modification. P-T estimates from these garnets may represent conditions during contact metamorphism despite the proximity of reported alteration (Brock & Brock, 1981).

The major element zoning patterns in garnets from samples collected adjacent to the Peach Lake Complex are similar to garnets from granite aureoles in that an increase in Ca and decrease in Mn are seen near the rim of these garnets. The magnitude of change in these elements however, is not as large as that seen in garnets from granite aureoles and no textural overgrowth is observed. The similarity of P-T estimates using these garnets to estimates from granite aureoles, as well as the presence of kyanite and staurolite in Peach Lake samples, suggests that the original contact assemblage may have been modified by the later metamorphism.

Fluid Inclusions

Two distinct occurrences of CO₂-rich fluid inclusions can be recognized based on petrologic and microthermometric information collected from the Manhattan Schist in the northeastern Manhattan Prong. By combining information from fluid inclusions with data from mineral equilibria, constraints on the tectonic evolution of this region can be obtained. Detailed textural analysis of decrepitated fluid inclusions also provides

constraints on the mechanisms that modify fluid inclusions during multiple metamorphic events.

Stage A

FIA-A fluid inclusions are found in the cores of both regional garnet and garnet that has been modified by contact metamorphism. Based on their location and random distribution these inclusions are interpreted to be primary, entrapped during growth of the garnet. Garnet is a very brittle material and, unlike quartz, may not be subject to crystal-plastic recrystallization. Thus, even at high grade metamorphic conditions stretching or deformation of fluid inclusions may not occur. Because modification of the inclusion volume after entrapment is probably negligible, these fluid inclusions are thought to be representative of entrapment conditions.

Representative CO₂-N₂ isochores for Stage A fluid inclusions have densities that range from approximately 0.56 g/cc to 0.83 g/cc and pass below the P-T estimates recorded by garnet-biotite and garnet-plagioclase thermobarometers (Fig 19).

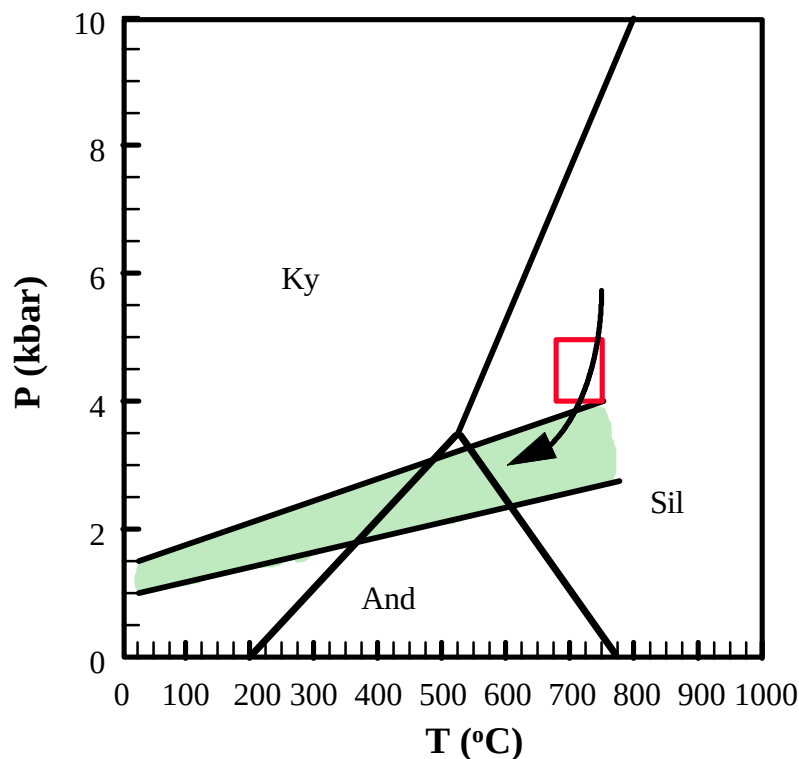


Figure 19 . Pressure-temperature plot showing range of representative isochores of CO₂-rich fluid inclusions in regionally metamorphosed garnets (FIA-A). P-T estimates of regional metamorphism from mineral equilibria are represented by the red box. Black arrow shows suggested P-T path during regional metamorphism.

This situation is commonly reported by workers studying CO₂-rich fluid inclusions in high grade terranes and several explanations have been proposed. The presence of minor amounts of H₂O which are not easily identified optically can shift isochores to higher pressure (Touret and Hansteen, 1988; Brown and Lamb, 1986; Lamb et al., 1991). Estimates of the amount of H₂O that may be present in fluid inclusions and not be detected, range from 10 mole % (Touret and Hansteen, 1988) to as high as 36 mole % (Lamb et al., 1987). Touret (1974) estimates a 1 to 2 kbar addition to the measured CO₂ pressure to compensate for the presence of H₂O. The removal of water from inclusions through reactions involving hydrous daughter minerals such as phlogopite has also been reported (Touret and Hansteen, 1988). Another mechanism to remove water is the preferential leaking of water by bulk diffusion and selective diffusion along dislocations and twin boundaries (Hall and Sterner, 1993).

Stage B

FIA-B fluid inclusions are found in the cores of garnets that have been modified by contact metamorphism and are characterized by fractures that originate at inclusion walls and extend into the surrounding host mineral. The similarity in occurrence, shape and composition of these inclusions with FIA-A inclusions suggests that they are reequilibrated FIA-A inclusions. Representative $\text{CO}_2\text{-N}_2$ isochores from these inclusions range from 0.71 g/cc to 0.90 g/cc. These isochores are at a higher density than FIA-A inclusions which suggests that some FIA-A inclusions reequilibrated toward the P-T conditions that prevailed during contact metamorphism (Fig. 20).

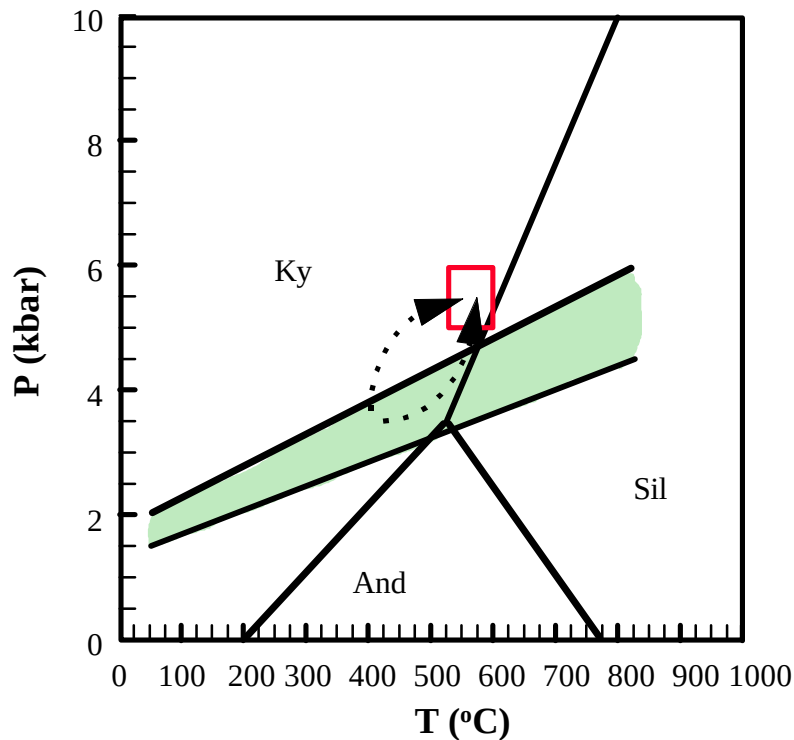


Figure 20 . Pressure-temperature plot showing range of representative isochores of CO_2 -rich fluid inclusions in contact metamorphosed garnets (FIA-B,C,D,E). P-T estimates of regional metamorphism from mineral equilibria are represented by the red box. Black arrows show suggested P-T path during overprinting metamorphism.

Re-equilibration of fluid inclusions may occur when the internal pressure of the inclusion is different from the external pressure. This causes the density of the fluid within the inclusion to change due to leaking or as a result of a change in volume of the inclusion. Several experimental studies have documented changes in the morphology as well as the density of synthetic fluid inclusions in quartz after reequilibration (Pecher, 1981; Sterner

and Bodnar, 1989; Vityk et al., 1994, Vityk et al., 1995). These studies agree that a relationship exists between inclusion morphology and the P-T path followed by the inclusion. Sterner and Bodnar (1989) observed that the morphology of inclusions reequilibrated under conditions of decompression (internal overpressure) were very different from inclusions reequilibrated under conditions of compression (internal underpressure). Furthermore, Vityk et al. (1994) concluded that the intensity of reequilibration features shows an inverse relationship to inclusion volume.

Characteristics of synthetic inclusions in quartz reequilibrated under conditions of internal *underpressure* include a 3-dimensional array of numerous tiny inclusions and fractures surrounding a central inclusion, referred to as ‘implosion halos’ (Fig. 21) (Sterner and Bodnar, 1989). Vityk and Bodnar (1995) report fractures and the presence of oriented planar arrays of numerous tiny secondary inclusions, termed ‘decrepitation clusters’, surrounding a central inclusion from synthetic inclusions in quartz reequilibrated under conditions of internal *overpressure* (Fig. 22). Similar textures were reported by Vityk et al. (1995) for CH₄ inclusions in natural quartz crystals from the Ukrainian Folded Carpathians (Fig. 23). Based on a comparison of fluid inclusion reequilibration textures produced in the laboratory with textures in natural samples, they concluded that these textures were produced by leaking and refilling under conditions of *uplift* (overpressure) (Vityk et al., 1995).

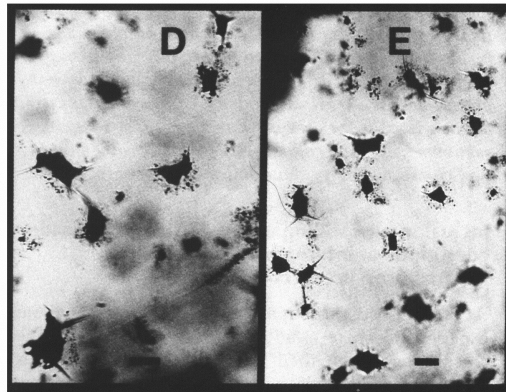


Figure 21. Photomicrographs D and E are synthetic aqueous inclusions in quartz that were experimentally reequilibrated under conditions of underpressure (Sterner and Bodnar, 1989). Scale bar represents 25 μm .

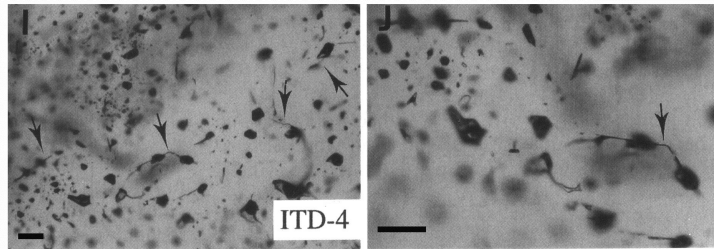


Figure 22. Photomicrographs I and J are synthetic aqueous inclusions in quartz that were experimentally reequilibrated under conditions of overpressure (Vityk and Bodnar, 1995). Scale bar represents 55 μm in I and 40 μm in J.

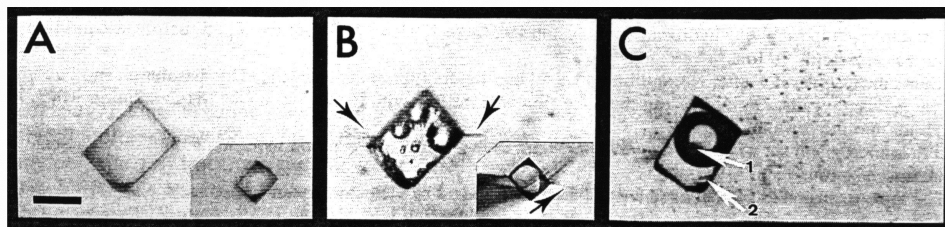


Figure 23. Photomicrographs A, B and C are natural methane inclusions in quartz that were experimentally reequilibrated under conditions of overpressure (Vityk et al., 1995). Scale bar represents 20 μm . Black arrows point to fractures.

Furthermore, natural aqueous inclusions experimentally reequilibrated at 5 kbar produced intense starlike textures (Fig. 24).

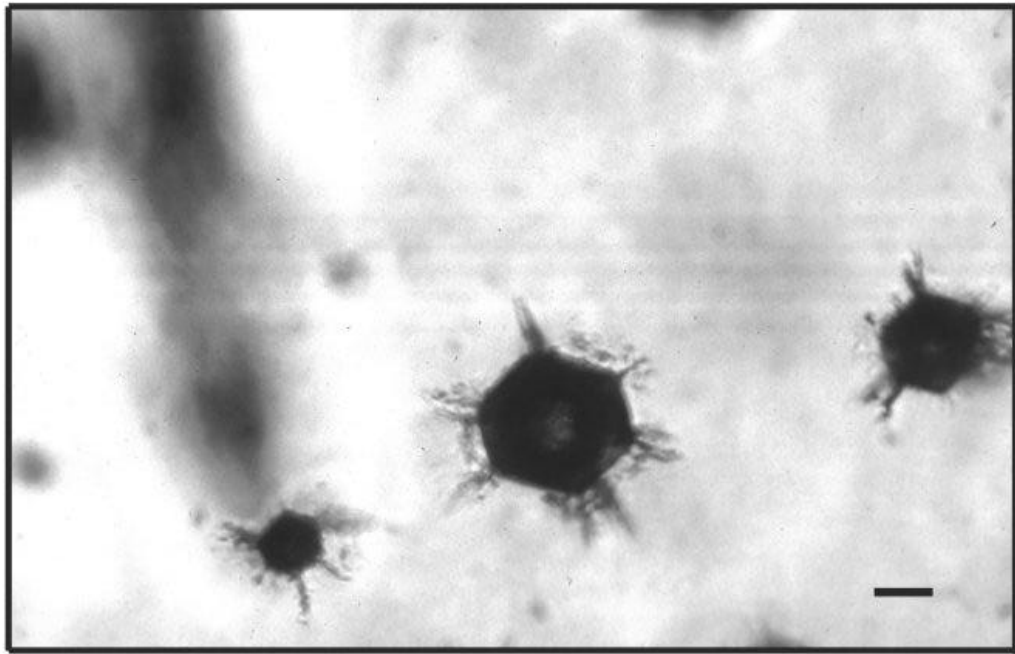


Figure 20. Photomicrograph of natural aqueous inclusions in quartz that have been experimentally re-equilibrated under 5 kbar of underpressure (Vityk et al., 1994). Scale bar represents 10μ .

Similarities in morphology of inclusions that have been reequilibrated under different conditions suggest that changes in the morphology of an inclusion may be dependent on other factors besides reequilibration conditions (i.e. composition of inclusion fluid and host mineral).

Reequilibration textures of CO_2 -rich fluid inclusions in garnets from the Manhattan Schist consist of thin, hair-like fractures that protrude from the corners of inclusions. No secondary clusters of inclusions were observed along these fractures. These textures are very similar to the starlike textures reported by Vityk et al. (1994) (Fig 24) from inclusions experimentally reequilibrated under conditions of underpressure. Results from geothermobarometry provide independent evidence that inclusions from this study were reequilibrated during compression and may have been subject to as much as 2 kbar of underpressure.

In addition to morphological changes, reequilibrated fluid inclusions may undergo changes in density. In experiments involving H_2O inclusions in synthetic quartz, Sterner

and Bodnar (1989) reported that during conditions of both underpressure and overpressure densities of inclusions changed towards the final P-T conditions, yet no inclusions were found that had totally reequilibrated. Vityk et al. (1995) reported a density increase for natural CH₄ fluid inclusions in quartz that were experimentally subjected to about 4 kbar underpressure resulting in a decrease in inclusion volume due to plastic deformation. An increase in density, up to $\rho \sim 0.90$ g/cc (from $\rho \sim 0.83$ g/cc), was observed in reequilibrated fluid inclusions of this study. This increase in fluid density along with the observations of textural decrepitation suggest that these inclusions may have reequilibrated during brittle compressive failure of the garnet during shearing which resulted in a decrease in the volume of inclusions.

FIA-C, FIA-D and FIA-E fluid inclusions are also interpreted to have formed during Stage B. FIA-C fluid inclusions are found along healed fracture planes near the rim of garnets that have been modified by contact metamorphism and shearing. Although these inclusions are secondary, their density ($\rho = 0.90$ g/cc) is similar to other Stage B inclusions. FIA-D inclusions occur in plagioclase that grew during contact metamorphism and shearing. Fluid inclusions in plagioclase have an average density of $\rho = 0.94$ g/cc and are interpreted to be primary based on their location along twin planes. Fluid inclusions in quartz (FIA-E) have an average density of $\rho = 0.91$ g/cc and are interpreted to be secondary based on their location along healed fracture planes. Based on the similarity in densities and textural relationships, all Stage B inclusions are interpreted to have formed at essentially the same time, during the reequilibration of Type A inclusions, associated with the later episode of shearing and contact metamorphism.

Source of the CO₂

CO₂-rich fluid inclusions in garnets have been reported from several localities. Perhaps the best studied occurrence is from the granulite facies terrane of Southwest India (Touret and Hansteen, 1988; Srikantappa et al., 1992). Two types of CO₂-rich fluid inclusion assemblages are recognized in garnets from the Doddabetta charnockite complex; the first is described as irregular clusters of negative crystal-shaped inclusions concentrated in the core and the second is described as tubular to vermicular shaped inclusions occurring along healed fractures (Srikantappa et al., 1992). Solid, highly

birefringent phases, identified as calcite in some inclusions, are reported to occur in both types (Srikantappa et al., 1992). The similarity of these inclusions to inclusions from this study is remarkable and initially suggests a common origin. Mineralogically and tectonically, however, the two terranes are quite different. Enderbitic rocks (plagioclase-quartz-orthopyroxene-garnet-biotite) of the Doddabetta complex record peak metamorphic P-T conditions of about 750 °C and 7 to 10 kbar (Srikantappa et al., 1992) whereas peak regional metamorphic conditions for the Manhattan Schist are estimated to have occurred at much lower pressures. Srikantappa et al., 1992 suggest that abundant, trailbound CO₂ inclusions in deformed and partially recrystallized quartz and plagioclase are related to shearing. Fluids in these secondary inclusions are thought to represent a combination of re-trapped CO₂ from decrepitated primary inclusions and fluids from a deep-seated igneous or sedimentary source (Touret and Hansteen, 1988; Srikantappa et al., 1992). The proximity of the Inwood Marble to the fluid inclusion-bearing rocks of the eastern Manhattan Prong suggests that degassing of the marble during regional metamorphism and again during subsequent shearing may be the source of CO₂ in the inclusions.

Tectonic Implications

Results of this study provide constraints on tectonic models proposed for the Manhattan Prong as well as insight into the mechanisms that modify fluid inclusions and garnet zoning during multiple metamorphic events. Estimates of P-T conditions from the Taconic 2nd sillimanite zone in the eastern Manhattan Prong are in good agreement with estimates reported by Whitney et al., (1996) for rocks just to the north in Dutchess County, NY.

Based on low T estimates and the presence of kyanite and staurolite, mineralogy of rocks adjacent to the Peach Lake Complex may have been modified by later metamorphism. Temperature estimates from rocks within the aureole of the Croton Falls Complex are higher and come from samples that do not contain kyanite or staurolite; therefore, these estimates may represent metamorphic conditions during intrusion.

Pressure estimates from the aureole of the Croton Falls Complex are similar to regional pressure estimates, unlike results predicted by the model of Waldron (1986). One

possible explanation is that the Croton Falls Complex (and Peach Lake Complex) were intruded at a higher structural level. Their occurrence at the same level as the Cortlandt Complex today may be a result of tilting and erosion.

P-T estimates associated with an episode of shearing and intrusion at ~350 Ma are at a lower temperature, but higher pressure, than regional estimates. Likewise, isochores for CO₂-rich fluid inclusions formed during this overprinting are at a higher density than isochores for inclusions formed during regional metamorphism. Where modified, the regional assemblage shows both textural and chemical changes. Garnet overgrowths have elevated concentrations of Ca and are depleted in Mn, Sc and Y, and primary CO₂-rich fluid inclusions in garnets have been reequilibrated to higher density. Petrologic evidence for rapid uplift of the Rowe-Hawley belt of western Connecticut, as reported by Hames *et al.* (1989), is not found in the northeastern Manhattan Prong, suggesting that these terranes may have been separated in the Devonian.

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Appendices

Appendix I:	Microprobe	Analyses of	Garnet			
sample#	ms3bG2-5	ms3bG2tr5	ms3bG3-7	ms3bG3-58	ms3bG1-4	ms5a-g3
location	core	rim	core	rim	core	rim
SiO ₂	37.818	38.048	38	38.092	38.186	38.387
TiO ₂	0	0.109	0.11	0.119	0.006	0
Al ₂ O ₃	21.992	21.713	21.041	20.966	21.285	21.05
FeO	33.028	33.858	35.11	32.3	33.092	35.223
MnO	4.954	2.22	2.159	3.122	5.221	3.91
MgO	3.726	3.626	4.135	3.479	3.692	2.212
CaO	1.4	3.008	1.069	2.875	1.441	2.12
total	102.918	102.582	101.66	101.88	102.923	102.902
Si	2.993	2.975	3.003	3.02	2.992	3.02
Ti	0	0.006	0.007	0.007	0	0
Al	1.999	2.001	1.96	1.959	1.996	1.95
	1.999	2.007	1.967	1.966	1.996	1.95
Fe	2.139	2.214	2.32	2.142	2.168	2.32
Mn	0.337	0.147	0.145	0.21	0.344	0.26
Mg	0.417	0.423	0.487	0.411	0.431	0.26
Ca	0.119	0.252	0.091	0.244	0.121	0.18
	3.012	3.036	3.043	3.007	3.064	3.02
X%						
alm	71.034	72.93	76.264	71.229	70.7	76.54
spes	11.179	4.84	4.75	6.973	11.3	8.63
pyr	13.842	13.92	16.011	13.676	14.06	8.6
gros	3.945	8.3	2.975	8.123	3.94	5.93
(Fe/Fe+Mg)	0.837	0.84	0.826	0.839	0.834	0.9

Microprobe	Analyses of		Garnet			
sample#	ms5a-g13	ms4G1-gt1	ms4G1-gt18	ms2aG4-25	ms2aG4-5	ms2aG6-1
location	core	rim	core	rim	core	rim
SiO2	38.485	37.249	37.068	38.233	38.304	38.048
TiO2	0	0.12	0.118	0	0	0
Al2O3	21.245	20.13	20.239	21.469	22.01	21.536
FeO	34.03	36.65	36.45	35.003	34.4	36.297
MnO	4.054	2.164	3.285	2.091	2.066	2.161
MgO	3.585	2.58	2.614	4.532	4.712	3.625
CaO	1.085	1.54	0.991	1.215	1.129	1.138
total	102.484	100.433	100.76	102.543	102.61	102.85
Si	3.02	3.02	3	2.988	2.98	2.985
Ti	0	0.01	0.01	0	0	0
Al	1.96	1.92	1.93	1.978	2.018	1.991
	1.96	1.93	1.94	1.978	2.018	1.991
Fe	2.23	2.48	2.47	2.288	2.282	2.381
Mn	0.27	0.15	0.23	0.138	0.137	0.144
Mg	0.42	0.31	0.32	0.528	0.512	0.424
Ca	0.09	0.13	0.09	0.102	0.092	0.096
	3.01	3.07	3.11	3.056	3.023	3.045
X%						
alm	74.11	80.69	79.75	74.86	74.234	78.217
spes	8.94	4.83	7.28	4.53	4.516	4.716
pyr	13.92	10.13	10.2	17.28	18.128	13.925
gros	3.03	4.35	2.78	3.33	3.122	3.142
(Fe/Fe+Mg)	0.84	0.89	0.89	0.812	0.804	0.849

Microprobe	Analyses of	Garnet				
sample#	ms2aG6-3	MP9gt2	CF3-gt3	pl11-g1	pl11-g8	pl11-g16
location	core	rim	rim	outer rim	inner rim	core
SiO2	38.443	37.82	39.78	38.69	39.55	39.264
TiO2	0	0.03	0.01	0	0	0
Al2O3	21.801	21.623	21.55	21.85	21.43	22.17
FeO	35.716	35.208	30.08	32.68	30.8	31.1
MnO	2.157	1.538	1.33	1.04	0.849	0.746
MgO	4.27	4.345	7.26	5.09	6.084	6.52
CaO	1.187	1.66	1.51	1.78	2.08	1.48
total	103.62	102.22	101.52	101.43	101.1	101.45
Si	2.981	2.968	2.98	3.02	3.07	3.03
Ti	0	0.002	0	0	0	0
Al	1.992	2	1.97	2.01	1.96	2.01
	1.992	2.002	1.97	2.01	1.96	2.01
Fe	2.316	2.311	2.15	2.13	2	2
Mn	0.142	0.102	0.13	0.07	0.06	0.05
Mg	0.494	0.508	0.23	0.59	0.7	0.75
Ca	0.099	0.14	0.58	0.15	0.17	0.12
	3.051	3.061	3.09	2.94	2.93	2.92
X%						
alm	75.938	75.49	69.49	72.47	68.19	68.5
spes	4.645	3.34	4.23	2.34	1.9	1.67
pyr	16.184	16.61	18.83	20.13	24	25.64
gros	3.233	4.56	7.45	5.07	5.9	4.21
(Fe/Fe+Mg)	0.824	0.82	0.86	0.78	0.74	0.73

Appendix II:	Microprobe	Analyses of	Biotite			
sample#	ms3bG2-13	ms3bG2-38	ms2aG4-6	ms2aG4-10	ms4G1-bt9	ms5-bt1
location	Inc	mtx	Inc	mtx	mtx	mtx
SiO2	36.326	36.745	35.662	36.099	35.346	36.554
TiO2	1.707	1.992	4.566	4.052	2.791	3.156
Al2O3	18.741	18.703	18.39	18.49	18.04	18.145
FeO	20.142	18.384	17.46	20.5	21.597	21.355
MnO	0.056	0.013	0.066	0.047	0.141	0.122
MgO	9.609	11.311	10.37	8.442	7.8	7.922
CaO	0.085	0.029	0.017	0	0.057	0
Na2O	0.21	0.189	0.175	0.116	0.191	0.058
K2O	8.095	8.684	9.003	9.253	8.661	9.069
Cl	0.039	0.024	0.064	0.019	0.019	0
F	0	0	0.418	0.291	0.423	0
total	95.01	96.074	96.191	97.309	95.07	96.38
formulas calculated on the basis of 22 oxygens						
Si	5.511	5.479	5.347	5.411	5.46	5.53
Al(IV)	2.489	2.521	2.653	2.565	2.54	2.47
Ti	0.195	0.223	0.515	0.402	0.32	0.36
Al(VI)	0.861	0.765	0.595	0.796	0.75	0.76
Fe	2.555	2.292	2.189	2.616	2.79	2.7
Mn	0.007	0.002	0.008	0.002	0.02	0.02
Mg	2.173	2.514	2.318	1.771	1.8	1.79
Ca	0.014	0.005	0.003	0.005	0.01	0
Na	0.062	0.055	0.051	0.012	0.06	0.02
K	1.567	1.652	1.722	1.768	1.71	1.75

Microprobe	Analyses of	Biotite				
sample#	ms5-bt9	mp9-bt1	mp102-bt7	pl11-bt31	cf3-bt11	
location	Inc	mtx	mtx	mtx	mtx	
SiO2	36.812	36.25	35.489	38.501	37.69	
TiO2	2.166	3.52	2.238	1.3	3.22	
Al2O3	17.937	18.567	18.103	19.09	20.01	
FeO	18.019	20.395	22.718	14.02	9.8	
MnO	0.125	0.092	0.166	0	0	
MgO	11.729	9.464	7.638	14.71	17.42	
CaO	0	0.04	0.011	0	0	
Na2O	0.213	0.21	0.136	0.18	0.77	
K2O	8.965	9.16	8.646	8.143	7.31	
Cl	0	0	0.012	0.016	0.03	
F	0	0	0.526	0.092	0.22	
total	95.97	97.91	95.68	96.052	96.46	
formulas calculated on the basis of 22 oxygens						
Si	5.5	5.39	5.48	5.582	5.34	
Al(IV)	2.5	2.61	2.52	2.418	2.656	
Ti	0.24	0.394	0.26	0.141	0.343	
Al(VI)	0.66	0.644	0.77	0.845	0.687	
Fe	2.25	2.536	2.93	1.701	1.162	
Mn	0.02	0.012	0.02	0	0	
Mg	2.61	2.098	1.76	3.18	3.682	
Ca	0	0.006	0	0	0	
Na	0.06	0.06	0.04	0.05	0.212	
K	1.71	1.74	1.7	1.51	1.322	
Fe/(Fe+Mg)	0.46	0.55	0.62	0.35	0.24	

Appendix III:	Microprobe	Analyses of	Muscovite			
	ms3bG2-1	ms3bG1-8	ms2aG4-13	mp6-3	mp9-7	mp102-12
SiO2	45.677	46.713	46.173	45.37	46.09	46.418
TiO2	0.58	0.878	1.155	0.481	0.708	0.497
Al2O3	33.448	33.471	34.07	34.95	33.875	33.576
FeO	2.74	3.135	2.399	1.183	1.448	2.919
MnO	0	0.037	0.019	0.047	0.028	0.024
MgO	0.769	0.788	0.57	0.593	0.775	0.745
CaO	0	0.027	0.054	0	0.02	0.003
Na2O	0.737	0.731	0.463	0.97	0.64	0.783
K2O	9.711	9.544	10.03	9.59	9.23	9.738
Cl	0	0	0.064	0.019	0.019	0
F	0.02	0.04	0.03	0.291	0.414	0.214
total	93.682	95.364	95.027	93.494	93.247	94.917
formulas calculated on the basis of 22 oxygens						
Si	6.214	6.245	6.191	6.153	6.257	6.246
Al(IV)	1.786	1.755	1.809	1.847	1.743	1.754
Ti	0.059	0.088	0.116	0.049	0.072	0.05
Al(VI)	3.577	3.518	3.574	3.739	3.677	3.571
Fe	0.312	0.35	0.269	0.134	0.164	0.328
Mn	0	0.004	0.002	0.005	0.003	0.003
Mg	0.156	0.157	0.114	0.12	0.157	0.149
Ca	0	0.004	0.008	0	0.003	0
Na	0.194	0.189	0.12	0.255	0.168	0.204
K	1.685	1.628	1.716	1.659	1.599	1.672
K/K+Na+Ca	0.897	0.894	0.931	0.867	0.903	0.891
Na/K+Na+Ca	0.103	0.104	0.065	0.133	0.095	0.109
Ca/K+Na+Ca	0.000	0.002	0.004	0.000	0.002	0.000
Fe/Fe+Mg	0.667	0.690	0.702	0.528	0.511	0.688

Appendix IV:	Microprobe	Analyses of	Feldspar			
sample#	ms3bG3-8	ms3bG3-46	ms3bG3-48	ms2aG4-16	ms5-pl26	ms5-pl27
location	Inc	rim	core	core	rim	core
SiO2	62.06	61.33	61.06	62.41	61.5	60.95
TiO2	0	0	0	0	0	0
Al2O3	23.65	24.2	24.7	25	25.13	25.28
FeO	0	0	0	0	0	0
MgO	0	0	0	0	0	0
CaO	6.07	6.73	7.03	5.87	6.6	7.01
Na2O	8.15	7.85	7.69	8.39	8.1	7.74
K2O	0.15	0.03	0.06	0.13	0.09	0.1
total	100.07	100.15	100.53	101.8	101.4	101.08
formula based on 8 oxygens						
Si	2.75	2.72	2.7	2.68	2.7	2.68
Al	1.235	1.26	1.29	1.31	1.3	1.31
Ti	0	0	0	0	0	0
Fe	0	0	0	0	0	0
Mg	0	0	0	0	0	0
Ca	0.29	0.32	0.33	0.33	0.31	0.33
Na	0.7	0.67	0.66	0.68	0.69	0.66
K	0.01	0	0	0	0.01	0.01
X%						
An	28.91	32.08	33.45	32.4	30.87	33.2
Ab	70.21	67.73	66.16	67.2	68.6	66.24
Or	0.88	0.18	0.39	0.38	0.53	0.59

Microprobe sample#	Analyses of ms4G1-pl22	Feldspar mp9-pl13	mp102-pl13	pl11-pl23
location				
SiO2	63.5	61.97	62.5	61.77
TiO2	0.024	0	0	0
Al2O3	22.1	24.24	22.68	25.71
FeO	0	0.11	0.08	0
MgO	0	0.02	0	0
CaO	3.56	6.06	3.94	6.15
Na2O	9.42	7.95	9.72	6.55
K2O	0.02	0.05	0.09	0
total	98.67	100.4	99	100.32
formula based on 8 oxygens				
Si	2.84	2.73	2.8	2.72
Al	1.16	1.26	1.2	1.33
Ti	0	0	0	0
Fe	0	0	0	0
Mg	0	0	0	0
Ca	0.17	0.29	0.19	0.29
Na	0.82	0.68	0.84	0.56
K	0	0	0	0
X%				
An	17.27	29.55	18.22	65.84
Ab	82.65	70.16	81.31	34.16
Or	0.08	0.29	0.47	0

MS3B Garnet Traverse						
distance from rim (μm)	0	10	20	30	40	50
SiO2	38.867	39.063	38.798	38.357	38.258	38.306
Al2O3	21.606	21.711	21.578	21.51	21.522	21.34
TiO2	0.06	0.029	0.021	0.027	0.03	0.018
FeO	34.795	34.863	34.501	34.864	34.064	34.97
MnO	2.347	2.241	2.108	1.952	1.971	1.952
MgO	3.142	3.316	3.479	3.592	3.46	3.697
CaO	2.512	2.556	2.605	2.827	2.945	2.534
Sc2O3	0.031	0.024	0.023	0.022	0.014	0.011
Cr2O3	0.011	0.013	0.015	0.023	0.02	0.02
Y2O3	0.064	0.041	0.05	0.039	0.058	0.037
P2O5	0.015	0.003	0.013	0.01	0.016	0.023
total	103.45	103.86	103.191	103.223	102.358	102.908
Si	2.98	2.99	3.01	3.01	2.99	3.02
Al	2.01	2.01	1.97	1.97	2.01	1.96
Ti	0.00	0.00	0.00	0.00	0.00	0.00
Fe	2.30	2.32	2.32	2.33	2.29	2.29
Mn	0.16	0.15	0.14	0.14	0.15	0.14
Mg	0.42	0.44	0.47	0.48	0.47	0.50
Ca	0.13	0.10	0.09	0.09	0.09	0.09
ppm						
Sc	203.65	157.66	151.09	144.53	91.97	72.26
Cr	75.22	88.89	102.57	157.27	136.76	136.76
Y	504.84	323.42	394.41	307.64	457.52	291.86
P	70.39	14.08	61.00	46.92	75.08	107.93
X%						
alm	76.49	77.19	76.79	76.70	76.46	75.90
gro	4.26	3.39	3.00	2.94	3.01	3.01
pyr	14.00	14.58	15.47	15.71	15.67	16.38
sps	5.26	4.84	4.74	4.65	4.86	4.71
(Fe/Fe+Mg)	0.85	0.84	0.83	0.83	0.83	0.82

MS3B Garnet Traverse						
distance from rim (μm)	60	70	80	90	100	110
SiO ₂	38.723	39.027	38.549	38.598	38.753	38.296
Al ₂ O ₃	21.245	21.385	21.44	21.557	21.425	21.542
TiO ₂	0.012	0.014	0.004	0.018	0.011	0.017
FeO	34.622	33.907	33.782	33.11	33.436	32.941
MnO	2.081	2.214	2.718	3.276	3.996	4.113
MgO	3.601	3.698	3.617	3.649	3.739	3.692
CaO	2.844	2.637	2.752	2.797	1.928	1.818
Sc ₂ O ₃	0.015	0.021	0.015	0.037	0.055	0.038
Cr ₂ O ₃	0.021	0.008	0.024	0.01	0.018	0.008
Y ₂ O ₃	0.039	0	0.004	0.006	0.033	0.042
P ₂ O ₅	0.019	0.013	0.013	0.015	0.013	0.003
total	103.222	102.924	102.918	103.073	103.407	102.51
Si	3.01	3.03	3.01	3.00	3.01	3.00
Al	1.95	1.96	1.97	1.98	1.96	1.99
Ti	0.00	0.00	0.00	0.00	0.00	0.00
Fe	2.25	2.20	2.20	2.15	2.17	2.16
Mn	0.14	0.15	0.18	0.22	0.26	0.27
Mg	0.42	0.43	0.42	0.42	0.43	0.43
Ca	0.24	0.22	0.23	0.23	0.16	0.15
ppm						
Sc	98.54	137.96	98.54	243.07	361.31	249.64
Cr	143.60	54.70	164.11	68.38	123.08	54.70
Y	307.64	0.00	31.55	47.33	260.31	331.30
P	89.16	61.00	61.00	70.39	61.00	14.08
X%						
alm	73.99	73.52	72.64	71.18	71.72	71.58
gro	7.79	7.33	7.58	7.70	5.30	5.06
pyr	13.72	14.29	13.86	13.98	14.30	14.30
sps	4.50	4.86	5.92	7.13	8.68	9.05
(Fe/Fe+Mg)	0.84	0.84	0.84	0.84	0.83	0.83

MS3B Garnet Traverse						
distance from rim (μm)	120	130	140	150	160	170
SiO ₂	38.514	38.624	38.688	38.33	38.641	38.241
Al ₂ O ₃	21.366	21.419	21.44	21.441	21.372	21.253
TiO ₂	0.018	0.007	0.01	0.012	0.011	0.016
FeO	32.604	32.812	32.86	33.096	33.226	32.78
MnO	4.557	4.609	4.773	4.733	4.825	4.812
MgO	3.757	3.772	3.804	3.855	3.784	3.759
CaO	1.69	1.506	1.573	1.486	1.486	1.467
Sc ₂ O ₃	0.066	0.059	0.061	0.068	0.035	0.045
Cr ₂ O ₃	0.006	0.012	0.012	0.008	0.018	0.023
Y ₂ O ₃	0.055	0.079	0.107	0.106	0.085	0.104
P ₂ O ₅	0.011	0.024	0.024	0.04	0.026	0.019
total	102.644	102.923	103.352	103.175	103.509	102.519
Si	3.01	3.02	3.01	2.99	3.01	3.00
Al	1.97	1.97	1.97	1.97	1.96	1.97
Ti	0.00	0.00	0.00	0.00	0.00	0.00
Fe	2.13	2.14	2.14	2.16	2.16	2.15
Mn	0.30	0.30	0.31	0.31	0.32	0.32
Mg	0.44	0.44	0.44	0.45	0.44	0.44
Ca	0.14	0.13	0.13	0.12	0.12	0.12
ppm						
Sc	433.58	387.59	400.73	446.72	229.93	295.62
Cr	41.03	82.06	82.06	54.70	123.08	157.27
Y	433.85	623.17	844.04	836.15	670.50	820.37
P	51.62	112.62	112.62	187.70	122.00	89.16
X%						
alm	70.75	71.12	70.68	70.92	71.05	70.90
gro	4.70	4.18	4.33	4.08	4.07	4.07
pyr	14.53	14.58	14.59	14.73	14.42	14.49
sps	10.02	10.12	10.40	10.27	10.45	10.54
(Fe/Fe+Mg)	0.83	0.83	0.83	0.83	0.83	0.83

MS3B Garnet Traverse						
distance from rim (μm)	180	190	200	210	220	230
SiO2	38.037	38.782	38.532	38.614	38.278	38.618
Al2O3	21.26	21.282	21.346	21.232	21.551	21.172
TiO2	0.004	0.013	0.021	0.016	0.007	0.011
FeO	32.805	33.148	32.682	33.078	32.869	32.734
MnO	5.065	4.954	5.027	4.985	5.046	4.845
MgO	3.773	3.711	3.727	3.774	3.674	3.73
CaO	1.469	1.428	1.461	1.484	1.416	1.497
Sc2O3	0.055	0.056	0.042	0.043	0.062	0.057
Cr2O3	0.027	0.024	0.003	0.01	0.011	0.012
Y2O3	0.087	0.067	0.082	0.091	0.095	0.084
P2O5	0.028	0.008	0.026	0.014	0.012	0.018
total	102.61	103.473	102.949	103.341	103.021	102.778
Si	2.99	3.02	3.01	3.01	2.99	3.02
Al	1.97	1.95	1.97	1.95	1.99	1.95
Ti	0	0	0	0	0	0
Fe	2.16	2.16	2.14	2.16	2.15	2.14
Mn	0.34	0.33	0.33	0.33	0.33	0.32
Mg	0.44	0.43	0.43	0.44	0.43	0.44
Ca	0.12	0.12	0.12	0.12	0.12	0.13
ppm						
Sc	361.31	367.88	275.91	282.48	407.30	374.45
Cr	184.62	164.11	20.51	68.38	75.22	82.06
Y	686.27	528.51	646.83	717.83	749.38	662.61
P	131.39	37.54	122.00	65.69	56.31	84.46
X%						
alm	70.48	71.12	70.6	70.75	70.93	70.84
gro	4.04	3.93	4.04	4.07	3.91	4.15
pyr	14.45	14.19	14.35	14.39	14.13	14.39
sps	11.02	10.76	11	10.8	11.03	10.62
(Fe/Fe+Mg)	0.83	0.83	0.83	0.83	0.83	0.83

MS3B Garnet Traverse						
distance from rim (μm)	240	250	260	270	280	290
SiO ₂	38.458	38.905	37.933	38.053	38.446	38.697
Al ₂ O ₃	21.102	21.361	21.093	21.462	21.421	21.384
TiO ₂	0.006	0.007	0.014	0.033	0.005	0.031
FeO	32.383	32.489	32.526	33.479	33.131	32.409
MnO	5.364	4.998	5.109	5.469	5.243	5.16
MgO	3.498	3.69	3.649	2.731	3.639	3.792
CaO	1.485	1.475	1.435	1.461	1.422	1.446
Sc ₂ O ₃	0.04	0.052	0.058	0.049	0.057	0.065
Cr ₂ O ₃	0.021	0.015	0.018	0.02	0.023	0.016
Y ₂ O ₃	0.081	0.086	0.079	0.091	0.069	0.085
P ₂ O ₅	0.015	0.021	0.004	0.024	0.012	0.022
total	102.453	103.099	101.918	102.872	103.468	103.107
Si	3.02	3.03	3	3	3	3.02
Al	1.95	1.96	1.97	1.99	1.97	1.96
Ti	0	0	0	0	0	0
Fe	2.13	2.12	2.15	2.21	2.16	2.11
Mn	0.36	0.33	0.34	0.36	0.35	0.34
Mg	0.41	0.43	0.43	0.32	0.42	0.44
Ca	0.13	0.12	0.12	0.12	0.12	0.12
ppm						
Sc	262.77	341.61	381.02	321.90	374.45	427.01
Cr	143.60	102.57	123.08	136.76	157.27	109.41
Y	638.94	678.39	623.17	717.83	544.29	670.50
P	70.39	98.54	18.77	112.62	56.31	103.23
X%						
alm	70.47	70.6	70.64	73.17	70.87	70.08
gro	4.14	4.11	3.99	4.09	3.9	4.01
pyr	13.57	14.29	14.13	10.64	13.88	14.62
sps	11.82	11	11.24	12.11	11.36	11.3
(Fe/Fe+Mg)	0.84	0.83	0.83	0.87	0.84	0.83

MS3B Garnet Traverse						
distance from rim (μm)	300	310	320	330	350	360
SiO ₂	38.095	38.359	38.06	38.601	38.615	37.942
Al ₂ O ₃	21.249	21.052	21.003	21.305	21.375	21.041
TiO ₂	0.012	0.019	0.019	0.006	0.009	0.02
FeO	32.705	32.406	32.691	32.765	33.113	32.573
MnO	5.105	5.282	5.147	5.234	5.21	5.231
MgO	3.759	3.764	3.815	3.871	3.89	3.902
CaO	1.416	1.421	1.424	1.44	1.358	1.43
Sc ₂ O ₃	0.061	0.059	0.053	0.053	0.053	0.051
Cr ₂ O ₃	0.012	0.011	0.007	0.018	0.016	0.019
Y ₂ O ₃	0.081	0.082	0.072	0.077	0.057	0.087
P ₂ O ₅	0.015	0.025	0.015	0.015	0	0.019
total	102.51	102.48	102.306	103.385	103.696	102.315
Si	3	3.02	3	3.01	3	2.99
Al	1.97	1.95	1.95	1.96	1.96	1.96
Ti	0	0	0	0	0	0
Fe	2.15	2.13	2.16	2.13	2.15	2.15
Mn	0.34	0.35	0.34	0.35	0.34	0.35
Mg	0.44	0.44	0.45	0.45	0.45	0.46
Ca	0.12	0.12	0.12	0.12	0.11	0.12
ppm						
Sc	400.73	387.59	348.18	348.18	348.18	335.04
Cr	82.06	75.22	47.87	123.08	109.41	129.92
Y	638.94	646.83	567.95	607.39	449.63	686.27
P	70.39	117.31	70.39	70.39	0.00	89.16
X%						
alm	70.5	70.01	70.26	69.99	70.36	69.81
gro	3.91	3.93	3.92	3.94	3.7	3.93
pyr	14.44	14.5	14.62	14.74	14.73	14.91
sps	11.15	11.56	11.2	11.32	11.21	11.35
(Fe/Fe+Mg)	0.83	0.83	0.83	0.83	0.83	0.82

MS3B Garnet Traverse						
distance from rim (μm)	370	410	420	430	440	450
SiO ₂	37.21	38.213	38.383	38.585	38.569	38.288
Al ₂ O ₃	20.358	21.318	21.136	21.174	21.003	21.428
TiO ₂	1.021	0.005	0.017	0.014	0.016	0.014
FeO	30.717	32.471	32.485	32.566	32.702	32.181
MnO	4.767	5.332	5.272	5.071	5.198	5.111
MgO	3.62	3.904	3.886	3.827	3.97	3.904
CaO	1.346	1.467	1.419	1.44	1.437	1.409
Sc ₂ O ₃	0.06	0.049	0.057	0.049	0.058	0.061
Cr ₂ O ₃	0	0.013	0.012	0.012	0.01	0.009
Y ₂ O ₃	0.102	0.078	0.093	0.077	0.073	0.063
P ₂ O ₅	0.024	0.023	0.026	0.02	0.011	0.017
total	99.225	102.873	102.786	102.835	103.047	102.485
Si	3.01	2.99	3.01	3.02	3.02	3
Al	1.94	1.97	1.95	1.95	1.94	1.98
Ti	0	0	0	0	0	0
Fe	2.08	2.13	2.13	2.13	2.14	2.11
Mn	0.33	0.35	0.35	0.34	0.34	0.34
Mg	0.44	0.46	0.45	0.45	0.46	0.46
Ca	0.12	0.12	0.12	0.12	0.12	0.12
ppm						
Sc	394.16	321.90	374.45	321.90	381.02	400.73
Cr	0.00	88.89	82.06	82.06	68.38	61.54
Y	804.60	615.28	733.60	607.39	575.84	496.96
P	112.62	107.93	122.00	93.85	51.62	79.77
X%						
alm	70.25	69.52	69.76	70.23	69.75	69.77
gro	3.94	4.02	3.9	3.98	3.93	3.91
pyr	14.76	14.9	14.87	14.71	15.09	15.09
sps	11.04	11.56	11.47	11.08	11.23	11.22
(Fe/Fe+Mg)	0.83	0.82	0.82	0.83	0.82	0.82

MS3B Garnet Traverse						
distance from rim (μm)	460	470	490	500	510	520
SiO2	38.363	39.122	38.63	38.404	38.728	38.517
Al2O3	21.19	21.525	21.132	21.418	21.168	21.156
TiO2	0.013	0.021	0.011	0.008	0.014	0.012
FeO	32.35	32.317	32.355	32.9	32.694	32.89
MnO	5.257	5.141	5.216	5.122	5.308	5.233
MgO	3.936	4.012	3.881	3.955	3.855	3.935
CaO	1.405	1.478	1.407	1.41	1.408	1.439
Sc2O3	0.042	0.045	0.064	0.061	0.054	0.061
Cr2O3	0.01	0.01	0.012	0.01	0.015	0.015
Y2O3	0.077	0.054	0.08	0.089	0.073	0.082
P2O5	0.015	0	0.018	0.014	0	0.012
total	102.658	103.725	102.806	103.391	103.317	103.352
Si	3.01	3.02	3.02	2.99	3.02	3.01
Al	1.96	1.96	1.95	1.97	1.94	1.95
Ti	0	0	0	0	0	0
Fe	2.12	2.09	2.12	2.14	2.13	2.15
Mn	0.35	0.34	0.35	0.34	0.35	0.35
Mg	0.46	0.46	0.45	0.46	0.45	0.46
Ca	0.12	0.12	0.12	0.12	0.12	0.12
ppm						
Sc	275.91	295.62	420.44	400.73	354.74	400.73
Cr	68.38	68.38	82.06	68.38	102.57	102.57
Y	607.39	425.96	631.06	702.05	575.84	646.83
P	70.39	0.00	84.46	65.69	0.00	56.31
X%						
alm	69.58	69.4	69.79	70.08	69.94	69.91
gro	3.87	4.07	3.89	3.85	3.86	3.92
pyr	15.09	15.36	14.92	15.02	14.7	14.91
sps	11.45	11.18	11.4	11.05	11.5	11.27
(Fe/Fe+Mg)	0.82	0.82	0.82	0.82	0.83	0.82

MS3B Garnet Traverse						
distance from rim (μm)	530	550	560	570	580	590
SiO ₂	39.127	38.283	38.178	39.103	38.266	38.026
Al ₂ O ₃	21.499	21.347	21.105	21.424	21.084	21.199
TiO ₂	0.011	0.015	0.073	0.031	0.024	0.005
FeO	33.491	32.89	32.65	32.348	32.511	32.643
MnO	5.263	5.098	5.218	5.24	5.287	5.194
MgO	4.078	3.829	3.867	3.845	3.843	4.042
CaO	1.466	1.358	1.388	1.451	1.429	1.369
Sc ₂ O ₃	0.054	0.064	0.045	0.048	0.045	0.077
Cr ₂ O ₃	0.01	0.014	0.015	0.013	0.018	0.02
Y ₂ O ₃	0.064	0.086	0.082	0.045	0.075	0.058
P ₂ O ₅	0	0.017	0.02	0	0.012	0.018
total	105.063	103.001	102.641	103.548	102.594	102.651
Si	3	3	3	3.03	3.01	2.99
Al	1.94	1.97	1.95	1.96	1.95	1.96
Ti	0	0	0	0	0	0
Fe	2.15	2.15	2.15	2.1	2.14	2.14
Mn	0.34	0.34	0.35	0.34	0.35	0.35
Mg	0.47	0.45	0.45	0.44	0.45	0.47
Ca	0.12	0.11	0.12	0.12	0.12	0.12
ppm						
Sc	354.74	420.44	295.62	315.33	295.62	505.84
Cr	68.38	95.73	102.57	88.89	123.08	136.76
Y	504.84	678.39	646.83	354.97	591.61	457.52
P	0.00	79.77	93.85	0.00	56.31	84.46
X%						
alm	69.82	70.55	70.05	69.76	69.85	69.66
gro	3.92	3.73	3.82	4.01	3.93	3.74
pyr	15.15	14.64	14.79	14.78	14.72	15.38
sps	11.11	11.08	11.34	11.45	11.5	11.23
(Fe/Fe+Mg)	0.82	0.83	0.83	0.83	0.83	0.82

MS2A Garnet Traverse						
distance from rim (μm)	0.00	20.00	40.00	60.00	80.00	100.00
SiO2	37.66	37.10	38.02	37.92	37.59	38.42
Al2O3	21.56	21.23	21.18	21.10	21.41	21.20
TiO2	0.00	0.01	0.01	0.01	0.01	0.02
FeO	34.77	34.44	35.12	35.08	34.44	34.93
MnO	2.36	2.13	2.14	2.10	2.16	2.14
MgO	3.57	3.65	3.97	4.03	3.96	4.23
CaO	1.51	1.18	1.07	1.05	1.06	1.08
Sc2O3	0.04	0.03	0.04	0.04	0.03	0.04
Cr2O3	0.01	0.00	0.01	0.00	0.02	0.01
Y2O3	0.04	0.03	0.02	0.02	0.01	0.01
P2O5	0.01	0.05	0.03	0.06	0.06	0.08
total	101.51	99.87	101.67	101.45	100.79	102.20
Si	2.98	2.99	3.01	3.05	2.99	3.02
Al	2.01	2.01	1.97	1.97	2.01	1.96
Ti	0.00	0.00	0.00	0.00	0.00	0.00
Fe	2.30	2.32	2.32	2.33	2.29	2.29
Mn	0.16	0.15	0.14	0.14	0.15	0.14
Mg	0.42	0.44	0.47	0.48	0.47	0.50
Ca	0.13	0.10	0.09	0.09	0.09	0.09
ppm						
Sc	262.77	197.08	262.77	262.77	197.08	262.77
Cr	68.38	0.00	68.38	0.00	136.76	68.38
Y	315.53	236.65	157.76	157.76	78.88	78.88
P	46.92	234.62	140.77	281.55	281.55	375.39
X%						
alm	76.49	77.19	76.79	76.70	76.46	75.90
gro	4.26	3.39	3.00	2.94	3.01	3.01
pyr	14.00	14.58	15.47	15.71	15.67	16.38
sps	5.26	4.84	4.74	4.65	4.86	4.71
(Fe/Fe+Mg)	0.85	0.84	0.83	0.83	0.83	0.82

MS2A Garnet Traverse						
distance from rim (μm)	120.00	140.00	160.00	180.00	200.00	220.00
SiO2	38.38	37.75	37.49	38.07	37.86	37.47
Al2O3	21.37	21.34	21.44	21.50	21.39	21.32
TiO2	0.01	0.01	0.02	0.02	0.02	0.02
FeO	35.26	34.62	34.74	34.98	34.46	34.67
MnO	2.16	2.29	2.26	2.08	2.14	2.19
MgO	4.16	4.18	4.26	4.27	4.32	4.23
CaO	1.05	1.07	1.04	1.09	1.04	1.08
Sc2O3	0.04	0.03	0.04	0.03	0.04	0.04
Cr2O3	0.01	0.02	0.02	0.01	0.01	0.01
Y2O3	0.03	0.02	0.02	0.03	0.03	0.02
P2O5	0.08	0.06	0.06	0.07	0.05	0.07
total	102.54	101.40	101.38	102.19	101.36	101.12
Si	3.01	2.99	2.97	2.99	2.99	2.98
Al	1.97	1.99	2.00	1.99	1.99	2.00
Ti	0.00	0.00	0.00	0.00	0.00	0.00
Fe	2.31	2.29	2.30	2.30	2.28	2.31
Mn	0.14	0.15	0.15	0.14	0.14	0.15
Mg	0.49	0.49	0.50	0.50	0.51	0.50
Ca	0.09	0.09	0.09	0.09	0.09	0.09
ppm						
Sc	262.77	197.08	262.77	197.08	262.77	262.77
Cr	68.38	136.76	136.76	68.38	68.38	68.38
Y	236.65	157.76	157.76	236.65	236.65	157.76
P	375.39	281.55	281.55	328.47	234.62	328.47
X%						
alm	76.31	75.65	75.60	75.89	75.47	75.68
gro	2.91	3.00	2.90	3.03	2.92	3.02
pyr	16.05	16.28	16.52	16.51	16.87	16.46
sps	4.73	5.07	4.98	4.57	4.75	4.84
(Fe/Fe+Mg)	0.83	0.82	0.82	0.82	0.82	0.82

MS2A Garnet Traverse						
distance from rim (μm)	240.00	260.00	280.00	300.00	320.00	340.00
SiO2	37.27	38.38	38.02	37.32	37.11	37.79
Al2O3	21.48	21.59	21.53	21.53	21.41	21.60
TiO2	0.02	0.01	0.01	0.01	0.01	0.02
FeO	34.58	35.14	34.33	34.29	34.04	33.54
MnO	2.16	2.19	2.14	2.05	2.16	2.21
MgO	4.28	4.23	4.37	4.51	4.42	4.41
CaO	1.09	1.16	1.17	1.17	1.07	1.15
Sc2O3	0.04	0.03	0.05	0.03	0.04	0.04
Cr2O3	0.01	0.01	0.01	0.00	0.00	0.01
Y2O3	0.04	0.03	0.02	0.04	0.04	0.05
P2O5	0.06	0.04	0.05	0.06	0.05	0.04
total	101.07	102.83	101.72	101.02	100.36	100.90
Si	2.97	3.00	2.99	2.96	2.97	2.99
Al	2.01	1.99	2.00	2.02	2.02	2.02
Ti	0.00	0.00	0.00	0.00	0.00	0.00
Fe	2.30	2.29	2.26	2.28	2.28	2.22
Mn	0.15	0.15	0.14	0.14	0.15	0.15
Mg	0.51	0.49	0.51	0.53	0.53	0.52
Ca	0.09	0.10	0.10	0.10	0.09	0.10
ppm						
Sc	262.77	197.08	328.47	197.08	262.77	262.77
Cr	68.38	68.38	68.38	0.00	0.00	68.38
Y	315.53	236.65	157.76	315.53	315.53	394.41
P	281.55	187.70	234.62	281.55	234.62	187.70
X%						
alm	75.51	75.46	74.98	74.70	74.85	74.35
gro	3.05	3.20	3.27	3.27	3.01	3.27
pyr	16.66	16.26	17.01	17.51	17.33	17.43
sps	4.78	4.78	4.73	4.52	4.81	4.96
(Fe/Fe+Mg)	0.82	0.82	0.82	0.81	0.81	0.81

MS2A Garnet Traverse						
distance from rim (μm)	360.00	380.00	400.00	420.00	440.00	460.00
SiO2	37.73	37.97	38.35	37.40	37.81	38.06
Al2O3	21.66	21.29	21.45	21.64	21.43	21.21
TiO2	0.01	0.01	0.01	0.00	0.02	0.01
FeO	33.92	34.70	34.17	34.33	34.51	34.20
MnO	2.16	2.14	2.08	2.10	2.05	2.18
MgO	4.56	4.51	4.53	4.65	4.62	4.59
CaO	1.09	1.13	1.11	1.07	1.10	1.13
Sc2O3	0.04	0.04	0.03	0.03	0.04	0.05
Cr2O3	0.01	0.00	0.00	0.01	0.01	0.01
Y2O3	0.05	0.05	0.07	0.07	0.08	0.08
P2O5	0.04	0.05	0.03	0.05	0.04	0.03
total	101.27	101.91	101.84	101.37	101.75	101.57
Si	2.98	2.99	3.01	2.96	2.98	3.00
Al	2.02	1.98	1.98	2.02	1.99	1.97
Ti	0.00	0.00	0.00	0.00	0.00	0.00
Fe	2.24	2.29	2.24	2.27	2.28	2.26
Mn	0.15	0.14	0.14	0.14	0.14	0.15
Mg	0.54	0.53	0.53	0.55	0.54	0.54
Ca	0.09	0.10	0.09	0.09	0.09	0.10
ppm						
Sc	262.77	262.77	197.08	197.08	262.77	328.47
Cr	68.38	0.00	0.00	68.38	68.38	68.38
Y	394.41	394.41	552.17	552.17	631.06	631.06
P	187.70	234.62	140.77	234.62	187.70	140.77
X%						
alm	74.33	74.86	74.65	74.44	74.65	74.29
gro	3.06	3.12	3.11	2.97	3.05	3.14
pyr	17.81	17.34	17.64	17.97	17.81	17.77
sps	4.79	4.68	4.60	4.61	4.49	4.80
(Fe/Fe+Mg)	0.81	0.81	0.81	0.81	0.81	0.81

MS2A Garnet Traverse						
distance from rim (μm)	480.00	500.00	520.00	540.00	560.00	580.00
SiO2	38.26	37.46	38.17	37.68	37.54	37.51
Al2O3	21.31	21.56	21.45	21.61	21.44	21.27
TiO2	0.02	0.03	0.01	0.00	0.03	0.02
FeO	34.52	34.54	34.75	34.56	33.90	34.10
MnO	2.19	2.07	2.08	2.10	2.02	2.06
MgO	4.65	4.49	4.58	4.73	4.68	4.55
CaO	1.18	1.11	1.12	1.13	1.17	1.16
Sc2O3	0.04	0.03	0.04	0.03	0.05	0.03
Cr2O3	0.01	0.01	0.01	0.01	0.01	0.00
Y2O3	0.09	0.07	0.08	0.08	0.11	0.08
P2O5	0.04	0.03	0.03	0.03	0.03	0.01
total	102.34	101.44	102.37	101.98	101.00	100.82
Si	3.00	2.97	2.99	2.97	2.98	2.98
Al	1.97	2.01	1.99	2.00	2.00	1.99
Ti	0.00	0.00	0.00	0.00	0.00	0.00
Fe	2.26	2.29	2.28	2.27	2.25	2.27
Mn	0.15	0.14	0.14	0.14	0.14	0.14
Mg	0.54	0.53	0.54	0.56	0.55	0.54
Ca	0.10	0.09	0.09	0.10	0.10	0.10
ppm						
Sc	262.77	197.08	262.77	197.08	328.47	197.08
Cr	68.38	68.38	68.38	68.38	68.38	0.00
Y	709.94	552.17	631.06	631.06	867.70	631.06
P	187.70	140.77	140.77	140.77	140.77	46.92
X%						
alm	74.17	74.99	74.80	74.22	74.04	74.48
gro	3.25	3.09	3.09	3.11	3.27	3.25
pyr	17.81	17.38	17.57	18.11	18.22	17.72
sps	4.77	4.55	4.53	4.57	4.47	4.56
(Fe/Fe+Mg)	0.81	0.81	0.81	0.80	0.80	0.81

MS2A Garnet Traverse						
distance from rim (μm)	600.00	620.00	640.00	660.00	680.00	700.00
SiO2	38.80	38.08	38.24	37.96	37.35	38.27
Al2O3	21.36	21.45	21.36	21.30	21.61	21.34
TiO2	0.01	0.01	0.00	0.01	0.00	0.01
FeO	34.51	34.11	34.65	34.22	34.03	34.38
MnO	2.11	2.00	2.16	2.12	2.19	2.09
MgO	4.59	4.64	4.66	4.57	4.58	4.66
CaO	1.13	1.07	1.13	1.11	1.12	1.13
Sc2O3	0.04	0.02	0.03	0.03	0.03	0.03
Cr2O3	0.01	0.02	0.01	0.02	0.01	0.02
Y2O3	0.09	0.08	0.08	0.08	0.07	0.08
P2O5	0.02	0.03	0.02	0.01	0.02	0.01
total	102.69	101.52	102.35	101.45	101.03	102.03
Si	3.02	2.99	3.00	3.00	2.96	3.00
Al	1.96	1.99	1.97	1.95	2.02	1.97
Ti	0.00	0.00	0.00	0.00	0.00	0.00
Fe	2.25	2.25	2.27	2.26	2.26	2.26
Mn	0.14	0.13	0.14	0.14	0.15	0.14
Mg	0.53	0.55	0.54	0.54	0.54	0.55
Ca	0.09	0.09	0.10	0.09	0.10	0.10
ppm						
Sc	262.77	131.39	197.08	197.08	197.08	197.08
Cr	68.38	136.76	68.38	136.76	68.38	136.76
Y	709.94	631.06	631.06	631.06	552.17	631.06
P	93.85	140.77	93.85	46.92	93.85	46.92
X%						
alm	74.57	74.51	74.37	74.50	74.22	74.33
gro	3.13	2.99	3.11	3.10	3.13	3.13
pyr	17.68	18.07	17.83	17.73	17.81	17.96
sps	4.62	4.42	4.70	4.67	4.84	4.58
(Fe/Fe+Mg)	0.81	0.81	0.81	0.81	0.81	0.81

MS2A Garnet Traverse						
distance from rim (μm)	720.00	740.00	760.00	780.00	800.00	820.00
SiO2	37.66	37.27	37.64	38.18	37.58	37.77
Al2O3	21.23	21.50	21.63	21.31	21.50	21.42
TiO2	0.00	0.01	0.00	0.01	0.00	0.00
FeO	34.24	34.40	34.04	34.35	34.20	34.43
MnO	2.19	2.07	2.15	2.00	2.05	2.07
MgO	4.60	4.61	4.61	4.65	4.54	4.81
CaO	1.14	1.09	1.15	1.10	1.10	1.09
Sc2O3	0.04	0.04	0.05	0.05	0.04	0.03
Cr2O3	0.01	0.02	0.01	0.02	0.02	0.02
Y2O3	0.07	0.08	0.06	0.07	0.06	0.08
P2O5	0.00	0.01	0.01	0.03	0.01	0.01
total	101.19	101.11	101.38	101.76	101.13	101.72
Si	2.99	2.96	2.97	3.00	2.98	2.98
Al	1.98	2.01	2.01	1.98	2.01	1.99
Ti	0.00	0.00	0.00	0.00	0.00	0.00
Fe	2.27	2.28	2.25	2.26	2.27	2.27
Mn	0.15	0.14	0.14	0.13	0.14	0.14
Mg	0.54	0.55	0.54	0.55	0.54	0.57
Ca	0.10	0.09	0.10	0.09	0.09	0.09
ppm						
Sc	262.77	262.77	328.47	328.47	262.77	197.08
Cr	68.38	136.76	68.38	136.76	136.76	136.76
Y	552.17	631.06	473.29	552.17	473.29	631.06
P	0.00	46.92	46.92	140.77	46.92	46.92
X%						
alm	74.24	74.60	74.15	74.55	74.71	74.05
gro	3.17	3.03	3.21	3.06	3.08	3.00
pyr	17.78	17.82	17.90	17.99	17.68	18.44
sps	4.81	4.55	4.74	4.40	4.54	4.51
(Fe/Fe+Mg)	0.81	0.81	0.81	0.81	0.81	0.80

MS2A Garnet Traverse						
distance from rim (μm)	840.00	860.00	880.00	900.00	920.00	940.00
SiO2	37.51	38.10	36.42	37.57	37.31	37.43
Al2O3	21.65	21.43	21.23	21.57	21.48	21.65
TiO2	0.01	0.00	0.01	0.01	0.00	0.00
FeO	34.41	34.62	33.96	33.53	34.12	34.09
MnO	2.11	2.09	2.06	2.15	2.07	2.12
MgO	4.70	4.67	4.21	4.62	4.64	4.63
CaO	1.13	1.12	1.11	1.14	1.11	1.08
Sc2O3	0.04	0.04	0.02	0.04	0.04	0.04
Cr2O3	0.02	0.01	0.02	0.01	0.01	0.01
Y2O3	0.07	0.08	0.05	0.07	0.07	0.07
P2O5	0.01	0.01	0.00	0.03	0.01	0.04
total	101.72	102.18	99.12	100.74	100.91	101.18
Si	2.96	2.99	2.95	2.98	2.97	2.97
Al	2.01	1.98	2.03	2.02	2.01	2.02
Ti	0.00	0.00	0.00	0.00	0.00	0.00
Fe	2.27	2.27	2.30	2.23	2.27	2.26
Mn	0.14	0.14	0.14	0.14	0.14	0.14
Mg	0.55	0.55	0.51	0.55	0.55	0.55
Ca	0.10	0.09	0.10	0.10	0.10	0.09
ppm						
Sc	262.77	262.77	131.39	262.77	262.77	262.77
Cr	136.76	68.38	136.76	68.38	68.38	68.38
Y	552.17	631.06	394.41	552.17	552.17	552.17
P	46.92	46.92	0.00	140.77	46.92	187.70
X%						
alm	74.20	74.46	75.51	73.85	74.32	74.31
gro	3.12	3.09	3.16	3.22	3.10	3.02
pyr	18.07	17.90	16.69	18.14	18.02	17.99
sps	4.61	4.55	4.64	4.80	4.57	4.68
(Fe/Fe+Mg)	0.80	0.81	0.82	0.80	0.81	0.81

MS2A Garnet Traverse						
distance from rim (μm)	960.00	980.00	1000.00			
SiO2	37.05	37.26	37.46			
Al2O3	21.51	21.57	21.54			
TiO2	0.02	0.01	0.01			
FeO	33.51	33.78	33.72			
MnO	2.02	2.05	2.07			
MgO	4.64	4.82	4.75			
CaO	1.08	1.05	1.13			
Sc2O3	0.05	0.05	0.04			
Cr2O3	0.01	0.01	0.01			
Y2O3	0.07	0.07	0.06			
P2O5	0.04	0.03	0.05			
total	100.05	100.71	100.84			
Si	2.97	2.96	2.97			
Al	2.03	2.02	2.01			
Ti	0.00	0.00	0.00			
Fe	2.24	2.25	2.24			
Mn	0.14	0.14	0.14			
Mg	0.55	0.57	0.56			
Ca	0.09	0.09	0.10			
ppm						
Sc	328.47	328.47	262.77			
Cr	68.38	68.38	68.38			
Y	552.17	552.17	473.29			
P	187.70	140.77	234.62			
X%						
alm	74.12	73.77	73.73			
gro	3.06	2.94	3.17			
pyr	18.29	18.76	18.52			
sps	4.53	4.53	4.58			
(Fe/Fe+Mg)	0.80	0.80	0.80			

Appendix VI: Fluid Inclusion Data

Mineral	Tm(°C)	Th(°C)	phase	size(μm)	shape
garnet	-57.4	19.6	liquid	5	negative
garnet	-57.3	19.0	liquid	4	negative
garnet	-57.7	18.0	liquid	5	negative
garnet	-57.5	6.5	liquid	7	decrep.
garnet	-57.5	19.6	liquid	8	negative
garnet	-57.5	18.6	liquid	5	decrep.
garnet	-57.6	12.2	liquid	7	decrep.
garnet	-57.5	19.6	liquid	5	negative
garnet	-57.5	16.5	liquid	4	negative
garnet	-57.6	-1.0	liquid	4	negative
garnet	-57.4	1.3	liquid	5	negative
garnet	-57.6	-1.3	liquid	7	negative
garnet	-57.4	20.6	liquid	8	negative
garnet	-57.3	5.6	liquid	4	decrep.
garnet	-57.2	23.1	liquid	8	tubular
garnet	-57.2	24.9	liquid	7	negative
garnet	-57.3	9.4	liquid	4	negative
garnet	-57.3	2.7	liquid	5	decrep.
garnet	-57.9	26.7	liquid	12	negative
garnet	-58.6	23.4	liquid	3	negative
garnet	-58.5	12.2	liquid	5	negative
garnet	-57.6	15	liquid	5	negative
garnet	-58.0	27	liquid	6	negative
garnet	-56.6	22.5	liquid	8	negative
garnet	-57.4	28.5	liquid	10	negative
garnet	-57.0	18.7	liquid	10	tubular
garnet	-57.5	22.5	liquid	8	irregular
garnet	-56.9	27.2	liquid	6	negative
garnet	-57.7	1.2	liquid	4	irregular
garnet	-57.7	-0.5	liquid	7	decrep.
garnet	-57.7	1.7	liquid	5	tubular
garnet	-57.7	-1.6	liquid	7	tubular
garnet	-57.1	16.5	liquid	15	tubular
plagioclase	-57.6	-17.2	liquid	15	negative
plagioclase	-57.6	-8.0	liquid	10	negative
plagioclase	-57.6	-8.2	liquid	8	negative
plagioclase	-57.6	-6.5	liquid	8	irregular
plagioclase	-57.6	-8.8	liquid	10	irregular
plagioclase	-57.6	-5.8	liquid	8	oval
plagioclase	-57.6	-6.3	liquid	6	oval
plagioclase	-57.6	-6.3	liquid	8	negative
plagioclase	-57.6	-5.1	liquid	8	negative
plagioclase	-57.6	-3.5	liquid	6	negative

plagioclase	-57.6	-4.4	liquid	5	negative
quartz	-57.8	-5.6	liquid	5	negative
quartz	-57.8	5.4	liquid	8	negative
quartz	-57.0	-5.4	liquid	3	negative
quartz	-57.0	-8.7	liquid	5	negative
quartz	-57.8	-7.3	liquid	5	negative
quartz	-57.8	3.1	liquid	8	tubular
quartz	-57.0	3.1	liquid	3	tubular
quartz	-57.5	-5.5	liquid	5	negative
quartz	-57.0	-5.5	liquid	4	negative
quartz	-57.0	-5.5	liquid	4	negative
quartz	-57.0	-5.0	liquid	5	negative
quartz	-56.6	10.1	liquid	8	negative
quartz	-56.6	8.6	liquid	6	negative
quartz	-56.6	10.4	liquid	3	negative
quartz	-56.6	8.3	liquid	5	negative
quartz	-56.6	9.6	liquid	4	negative
quartz	-56.6	17.1	liquid	4	negative
quartz	-56.6	17.1	liquid	5	negative
garnet	-60.0	12.0	liquid	2	negative
garnet	-61.5	17.1	liquid	5	negative
garnet	-61.1	17.7	liquid	4	negative
garnet	-59.9	17.7	liquid	4	negative
garnet	-61.6	18.5	liquid	5	negative
garnet	-61.5	15.1	liquid	3	negative
garnet	-61.1	15.9	liquid	4	negative
garnet	-59.9	9.4	liquid	4	negative
garnet	-60.2	9.0	liquid	3	negative
garnet	-60.2	12.5	liquid	4	negative
garnet	-58.8	2.8	liquid	3	decrep.
garnet	-58.8	16.7	liquid	3	negative
garnet	-58.8	15.8	liquid	6	oval
garnet	-58.0	18.5	liquid	4	negative
garnet	-58.8	24.7	liquid	2	oval
garnet	-58.8	25.0	liquid	4	oval
garnet	-58.8	25.4	liquid	3	negative
garnet	-58.8	11.1	liquid	3	negative
garnet	-58.5	15.5	liquid	5	negative
garnet	-58.5	16.1	liquid	5	negative
garnet	-58.5	23.2	liquid	3	negative
garnet	-58.5	21.2	liquid	2.5	negative
garnet	-58.5	21.6	liquid	3	negative
garnet	-57.5	13.7	liquid	5	decrep.
garnet	-58.8	21.3	liquid	3	negative
garnet	-58.8	25.3	liquid	5	negative
garnet	-58.8	21.1	liquid	2	irregular
garnet	-58.8	12.9	liquid	4	decrep.

garnet	-58.8	22.1	liquid	3	negative
garnet	-58.0	22.5	liquid	4	negative
garnet	-58.0	22.6	liquid	4	negative
garnet	-58.0	24.2	liquid	4	negative
garnet	-58.0	25.0	liquid	3	negative
garnet	-58.0	25.7	liquid	4	negative
garnet	-58.0	22.0	liquid	2	irregular

VITA

Adam Taylor Henry was born September 4, 1971 in Torrington, Connecticut. He graduated from the University of New Hampshire, Durham, New Hampshire in August, 1993 with a Bachelor's degree in Geology. After two years in parts unknown he returned to attend graduate school at Virginia Tech. He is going to enter the workforce as a geologist and hopefully wind up out west where the geology is bigger than life.