

**The microstructural and metamorphic history
preserved within garnet porphyroblasts
from southern Vermont and northwestern Massachusetts**

VOLUME I

Thesis submitted by

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in June 2004

for the degree of Doctor of Philosophy

in the School of Earth Sciences

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ACKNOWLEDGEMENTS

Firstly, I would like to thank my supervisor, Tim Bell, for his enthusiasm and encouragement throughout this project. Tim contributed significantly to the design of this project and has provided immeasurable assistance on the microscope helping me interpret inclusion geometries and reading and discussing numerous drafts of this thesis. I would also like to thank all the other members of SAMRI, past and present, who have helped contribute to my understanding of orogenesis in general and the development of the Appalachians in particular. I am especially grateful to Tom Evans and Peter Welch for introducing me to THERMOCALC and for providing me with datafiles and other assistance as I constructed the pseudosections in this thesis.

I would like to acknowledge Kevin Blake of the Advanced Analytical Centre at James Cook University for his help in preparing compositional zoning maps and for general assistance in using the microprobe. During my fieldwork I am grateful to have been able to use the rock cutting facilities at the University of Massachusetts and I would like to thank Mike Williams and Shelia Seaman for their help. I would like to thank Paul Karabinos of Williams College for suggesting I collect samples from the Devils Den area. I am also thankful to Scott Johnson for his constructive remarks on an early version of Section A, Neil Mancktelow for his comments on a version of Section B and David Hirsch for his very helpful review of a version of Section C.

During my PhD I was initially supported by a School of Earth Sciences Scholarship and later by a James Cook University Scholarship. Financial support used to cover the cost of research was partly provided by an Australian Research Council grant given to Tim

Bell. The School of Earth Sciences is also acknowledged for financial support used to cover basic research costs.

I would like to thank my parents, Garth and Mary Gavin, for their emotional and financial support throughout my academic career. Much as I missed New Zealand while I was studying in Townsville they ensured I never felt isolated from my family. Most of all I would like to thank my husband, James Leonard, for all his help. His practical assistance was invaluable during fieldwork and rock preparation and his emotional support has kept me sane. I could not have done this without him.

ABSTRACT

Garnet porphyroblasts from southern Vermont and northwestern Massachusetts typically preserve multiple generations of inclusion trails, reflecting a potentially complex deformation and metamorphic growth history. Textural discontinuities, such as inclusion trail truncations or deflection planes, are commonly preserved within these complex inclusion trails and they are dominantly sub-vertically and sub-horizontally oriented. This observation cannot be adequately explained using the rotational model of spiral inclusion trail formation, leading to the conclusion that the trails were formed by the inclusion of multiple sub-vertical and sub-horizontal foliations during episodic garnet growth without porphyroblast rotation. Foliation inflection/intersection axes preserved within porphyroblasts (FIAs) provide important information about the kinematics of deformation, particularly the direction of bulk shortening at the time they formed. Samples from this study preserve a succession of six FIA sets resulting from a progressive change in the direction of bulk shortening through time. The distribution of these FIA sets across the field area indicates that the deformation was heterogeneously partitioned and occurred at different scales throughout orogenesis. Localization of deformation is an important control on garnet growth and repartitioning during successive deformation events resulted in a heterogeneous spatial distribution of garnet growth through time. The episodic nature of garnet growth is reflected in compositional zoning anomalies in garnet porphyroblasts from the Hoosac Formation. Zones of manganese enrichment, accompanied by calcium depletion, reveal pauses in garnet growth that may have been accompanied by fluid infiltration, garnet dissolution-precipitation and metasomatism at crystal or greater scales. The metamorphic history of these samples was further investigated using P-T pseudosections constructed via THERMOCALC. The mineral assemblages predicted are in good agreement with the

observed mineralogy of the samples and estimates of P-T conditions at the time of garnet core growth were made using compositional isopleths based on microprobe analyses of garnet core composition. The samples do not show a clear relationship between the P-T data and the FIA data, suggesting that the preservation of different FIAs is not simply a function of P-T conditions. In samples where initial garnet appears to have occurred at temperature and/or pressure conditions higher than the minimum P-T conditions predicted for garnet stability, deformation probably played an essential role in garnet nucleation and growth. These “overstepped” samples indicate a progressive increase in pressure through the different phases of orogenesis.

This study reveals that garnet porphyroblasts in southern Vermont and northwestern Massachusetts grew during a complex history of deformation involving the production of multiple sub-horizontal and sub-vertical foliations with garnet growth primarily controlled by deformation partitioning, resulting in a heterogeneous spatial distribution through time. FIAs allow the relative age of different phases of garnet growth to be established and provide a framework for interpreting the relationship between deformation and metamorphism. Compositional zoning anomalies reflect the episodic nature of garnet growth and P-T modelling suggests that deformation took place under conditions of increasing pressure.

TABLE OF CONTENTS

Volume I

Statement of Access	ii
Statement of Sources	iii
Acknowledgements	iv
Abstract	vi
Table of Contents	viii

Introduction	xiii
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Section A: The orientation of textural discontinuities in garnets with complex spiral inclusion trails **A-1**

Abstract	A-3
1. Introduction	A-4
1.1 Rotational Model	A-5
1.2 Non-rotational Model	A-5
1.3 Textural discontinuities within inclusion spirals	A-8
1.4 Orientation of discontinuities	A-11
1.5 Geological setting	A-13
2. Methods	A-13
2.1 Sample descriptions	A-14
2.2 Measuring textural discontinuities	A-16
2.3 Foliation Inflection/Intersection Axis (FIA) Analysis	A-17
3. Results	A-18
4. Interpretation and Discussion	A-18
4.1 Textural Discontinuities	A-18
4.2 Mineral Preferred Orientations	A-21
4.3 FIA Analysis	A-21
4.4 Rotation vs. Non-rotation	A-23
5. Conclusions	A-24
References	A-25

Section B: Foliation Intersection/Inflection Axes in garnet porphyroblasts and the relationship between garnet growth and deformation **B-1**

Abstract	B-3
1. Introduction	B-4
1.1 Geological setting and metamorphic history	B-5
1.2 Complex spiral inclusion trails and FIAs	B-7
1.3 FIAs and the garnet isograd	B-8
2. Methods	B-9
2.1 FIA Analysis	B-9
3. Results	B-10
3.1 Multi-FIA Samples	B-10
4. Interpretation and Discussion	B-11

4.1	Defining FIA sets and correlating with previous studies	B-11
4.2	Continuity between matrix and inclusion trails	B-14
4.3	Taconic vs. Acadian FIA sets	B-16
4.4	Spatial distribution of FIAs and implications for metamorphism	B-19
5.	Conclusions	B-23
	References	B-25

Section C: Chemical zoning anomalies in garnet porphyroblasts displaying multiple phases of growth: their formation and relationship to textural discontinuities **C-1**

	Abstract	C-3
1.	Introduction	C-4
1.1	Manganese Zoning Anomalies	C-4
1.2	Textural Discontinuities	C-6
2.	Sample Descriptions	C-7
2.1	BG62	C-7
2.2	BG87	C-8
2.3	BG107A	C-9
2.4	BG108	C-9
3.	Compositional zoning	C-10
3.1	BG62	C-10
3.2	BG87	C-11
3.3	BG107A	C-12
3.4	BG108	C-12
4.	Interpretation and Discussion	C-13
4.1	Garnet dissolution and manganese enrichment	C-13
4.2	Manganese enrichment without garnet dissolution	C-15
4.3	Regional evidence for fluid infiltration	C-18
4.4	Open vs. closed system metamorphism: textural evidence	C-19
4.5	Intra-crystalline diffusion in garnet	C-20
4.6	Manganese enrichment accompanied by calcium depletion	C-22
4.7	The relationship between zoning anomalies and deformation	C-23
4.8	Timing the manganese enrichment	C-24
5.	Conclusions	C-25
	References	C-27

Section D: Pressure and temperature conditions during garnet growth in southeastern Vermont **D-1**

	Abstract	D-3
1.	Introduction	D-4
1.1	Previous P-T path work in the New England Appalachians	D-4
1.2	Foliation Intersection/Inflection Axes (FIAs)	D-5
1.3	THERMOCALC and P-T pseudosections	D-7
2.	Sample Descriptions	D-10
2.1	BG53	D-11

2.2	BG58B	D-11
2.3	BG59	D-12
2.4	BG62	D-12
2.5	BG87	D-12
2.6	BG107A	D-13
2.7	BG108	D-14
3.	P-T Pseudosections	D-14
3.1	Comparing pseudosections for different samples	D-16
3.2	Comparing the pseudosections to observed mineralogy	D-19
3.3	Isopleth intersections	D-23
4.	Garnet zoning	D-26
4.1	BG87, BG108, BG107A and BG62	D-26
4.2	BG58B and BG53	D-27
4.3	BG59	D-27
5.	P-T-t History	D-28
5.1	P-T and compositional zoning	D-28
5.2	P-T conditions during FIA development and the role of overstepping	D-31
5.3	Comparing garnet cores with peak P-T from matrix assemblages	D-35
6.	Conclusions	D-38
	References	D-40

Volume II

Section A: The orientation of textural discontinuities in garnets with complex spiral inclusion trails **A-1**

Table A-1: Trend and plunge of Foliation Intersection/Inflection Axes (FIAs) for selected samples.	A-3
Figure A-1: Diagram showing how curved inclusion trails can be produced without porphyroblast rotation.	A-4
Figure A-2: Diagram showing how orthogonal foliations can be produced.	A-5
Figure A-3: Diagram showing examples of textural discontinuities.	A-7
Figure A-4: Diagram showing how textural discontinuities can form in a rotating porphyroblast and a non-rotating porphyroblast.	A-8
Figure A-5: Diagram of a rhombododecahedron, a common garnet crystal form.	A-9
Figure A-6: Map showing the location of samples mentioned in the text.	A-10
Figure A-7: Equal area rose diagrams showing the pitch of discontinuities.	A-11

Section B: Foliation Intersection/Inflection Axes in garnet porphyroblasts and the relationship between garnet growth and deformation **B-1**

Table B-1: FIA orientation and allocated FIA set for each sample.	B-3
Table B-2: FIA orientations and allocated FIA sets for multi-FIA samples of Bell and Hickey (1997) and Bell et al. (1998).	B-4
Figure B-1: Map showing the location of samples.	B-5
Figure B-2: Equal-area rose diagrams showing total FIA data from southern Vermont and north-western Massachusetts.	B-6

Figure B-3: Diagram showing the sequence of FIAs preserved from the core to rim in multi-FIA samples.	B-7
Figure B-4: Rose diagrams and maps showing the spatial distribution of FIA sets.	B-8

Section C: Chemical zoning anomalies in garnet porphyroblasts displaying multiple phases of growth: their formation and relationship to textural discontinuities

Table C-1: Microprobe garnet analyses	C-3
Figure C-1: Map showing the location of samples mentioned in the text.	C-5
Figure C-2: Images of a garnet porphyroblast from sample BG62.	C-6
Figure C-3: Images of a garnet porphyroblast from sample BG87.	C-8
Figure C-4: An enlargement of the bottom right corner of the garnet porphyroblast in Figure C-3 (Sample BG87).	C-10
Figure C-5: Images of a garnet porphyroblast from sample BG87.	C-12
Figure C-6: Images of a garnet porphyroblast from sample BG107A.	C-14
Figure C-7: Images of a garnet porphyroblast from sample BG108.	C-16
Figure C-8: Photomicrograph showing part of a garnet porphyroblast from sample BG87.	C-18

Section D: Pressure and temperature conditions during garnet growth in southeastern Vermont

Table D-1: Mineral assemblages	D-3
Table D-2: Bulk rock compositions used to calculate P-T pseudosections.	D-4
Table D-3: Average garnet core compositions used to calculate isopleths.	D-4
Table D-4: Garnet core compositional isopleth intersections	D-5
Figure D-1: Map showing the location of samples from this study and of samples from earlier studies mentioned in Figure D-12.	D-6
Figure D-2: NCMnKFMASH Pseudosection for sample BG53.	D-7
Figure D-3: NCMnKFMASH Pseudosection for sample BG58B.	D-9
Figure D-4: NCMnKFMASH Pseudosection for sample BG59.	D-11
Figure D-5: NCMnKFMASH Pseudosection for sample BG62.	D-13
Figure D-6: NCMnKFMASH Pseudosection for sample BG87.	D-15
Figure D-7: NCMnKFMASH Pseudosection for sample BG107A.	D-17
Figure D-8: NCMnKFMASH Pseudosection for sample BG108.	D-19
Figure D-9: Electron microprobe compositional maps of a garnet porphyroblast from sample BG53.	D-21
Figure D-10: Electron microprobe compositional maps of a garnet porphyroblast from sample BG58B.	D-22
Figure D-11: Electron microprobe compositional maps of a garnet porphyroblast from sample BG59.	D-23
Figure D-12: Diagram comparing P-T results.	D-24

Appendices	X-1
Appendix 1: Sample location grid references	X-2
Appendix 2: Foliation Inflection/Intersection Axis (FIA) Analysis	X-5
Appendix 3: Textural Discontinuity Orientations	X-10
Appendix 4: Orientation of thin-sections prepared for this study	X-15
Appendix 5: Microprobe garnet analyses	X-17
Appendix 6: Calculating the amount of garnet dissolution needed to account for an observed manganese anomaly	X-32
Appendix 7: Length scale of diffusion calculations	X-37
Appendix 8: NCMnKFMASH Datafile	X-39
Appendix 9: Bulk rock XRF analyses	X-46
Appendix 10: Errors in compositional isopleth intersections	X-47
Appendix 11: Specimen collection list	X-52

INTRODUCTION

Understanding the relationships between deformation and metamorphism is crucial to understanding the process of orogenesis as a whole. The Appalachians in southern Vermont and northwestern Massachusetts are particularly suited to a study focusing on the relationships between metamorphism and deformation because of the remarkable structural and metamorphic history recorded as inclusion trails within the garnet porphyroblasts growing in these rocks. Many important microstructural and metamorphic studies have been carried out in southern Vermont and northwestern Massachusetts (e.g. Rosenfeld, 1968; Thompson et al., 1977; Karabinos, 1984; Armstrong et al., 1992; Vance & Holland, 1993; Bell et al., 1998; Bell & Welch, 2002) and these provided an excellent background to the present study. The main difference between the present study and previous work is that the same set of samples used for microstructural analysis were also used for electron microprobe mapping of compositional zoning and thermodynamic modelling of P-T conditions during garnet growth. This allows the integration of microstructural data with petrologic observations and P-T pseudosections and highlights the inter-relationship of deformation and metamorphism in this area. The study forms part of a larger ongoing research project by the Structure and Metamorphism Research Institute (SAMRI) at James Cook University that is investigating and integrating the structural, metamorphic and tectonic history of the Appalachian orogenic belt.

Thesis Format

The thesis consists of four sections, each written as stand-alone bodies of work with the intention that they will be submitted as papers for publication. The thesis structure aims to provide a logical progression from microstructural to metamorphic interpretations

and the metamorphic history preserved in the porphyroblasts is discussed in terms of the microstructural framework established. The main text of the thesis is in Volume I and figures and tables are presented in Volume II. References are given at the end of each section in Volume I and appendices are included at the end of Volume II.

Section A

The orientation of textural discontinuities in garnets with complex spiral inclusion trails

Textural discontinuities are common within the complex inclusion trails of ‘snowball’ garnets in southern Vermont and northwestern Massachusetts. Textural discontinuities may be truncations, where an inner foliation is truncated by a younger foliation in the rim of the garnet, commonly at a high angle, or deflection planes, where the inner foliation bends sharply before merging with the outer foliation at a low angle, resembling the differentiated zones of crenulation cleavages. Measurement of over 500 discontinuities in six samples indicates that they are dominantly sub-vertical and sub-horizontal features. This section discusses the formation of textural discontinuities and evaluates how well the observed features are explained by the rotational and non-rotational models for spiral inclusion trail development.

Section B

Foliation Inflection/Intersection Axes in garnet porphyroblasts and the relationship between deformation and garnet growth

The complex inclusion trails preserved in garnet porphyroblasts in this area indicate a history of multiple phases of deformation and garnet growth. Foliation inflection/intersection axes preserved in garnet porphyroblasts (FIAs) show a systematic

change in the direction of principal horizontal bulk shortening across the area through time in the form of a succession of six FIA sets. This section describes the spatial distribution of the different FIA sets and discusses the fundamental controls on garnet growth indicated by the demonstrated heterogeneous and episodic distribution of garnet growth.

Section C

Chemical zoning anomalies in garnet porphyroblasts displaying multiple phases of growth: their formation and relationship to textural discontinuities

Garnet porphyroblasts from the Hoosac Formation in southern Vermont have distinct textural core and rim zones associated with anomalous chemical zoning. The core-rim boundary is marked by a narrow area where there is a spectacular increase in manganese and by changes in calcium and magnesium zoning patterns. This section describes the different styles of zoning anomaly observed in four Hoosac garnets. Using these examples, the role of open versus closed system behaviour in developing the zoning anomalies is evaluated. The relationship between zoning anomalies and the formation of textural discontinuities is also examined.

Section D

Pressure-temperature conditions during garnet growth in southeastern Vermont

P-T pseudosections are an important tool for extracting information about the pressure and temperature conditions of garnet formation. In this section, THERMOCALC is used to produce P-T pseudosections for seven samples of pelitic garnet schist from the Hoosac formation of southeastern Vermont. The mineral assemblages predicted from the modelling are generally in good agreement with the observed mineralogy of the

samples and the pseudosections successfully model the garnet core compositions measured in six out of seven samples. Core compositional isopleths are used to estimate the P-T conditions of initial garnet growth and these results are discussed in relation to the FIA sets preserved in these samples.

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