

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

**VOLUME I**

Thesis submitted by

Bronwyn Patricia GAVIN BSc (Hons) *Canterbury, NZ*

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## 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.

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## 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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