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Tectono-metamorphic evolution of western Maine, Northern Appalachians, USA

Volume 1

Thesis submitted by
Ioan Vasile Sanislav BSc, MSc UAIC (Romania)
in July 2009

for the degree of Doctor of Philosophy
in the School of Earth and Environmental Sciences
James Cook University, Australia

CONTENT OF VOLUME 1

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INTRODUCTION AND THESIS OUTLINE

This thesis investigates the tectono-metamorphic evolution of a portion of the Northern Appalachians, located in Western Maine, USA. The region under study is located in the contact aureole of the Mooselookmeguntic pluton, which is one of the best-documented areas in the literature on the Northern Appalachians. Although, the region under study is quite small, the results presented in this thesis have considerable significance for the Maine-New Hampshire portion of the Northern Appalachians as well as for similar terranes in other parts of the world. The thesis integrates results from detailed microstructural measurements with electron microprobe analysis (EPMA) dating of monazite grains preserved as inclusions in staurolite porphyroblasts (and the matrix), thermobarometry and phase diagram modeling. This reveals a lengthy tectono-metamorphic history tightly associated with plutonism.

The thesis consists of four sections, each a stand-alone body of work intended for publication in international journals. The sections are ordered such that they progress in a logical fashion. Volume 1 contains the text and reference list, whilst Volume 2 contains the figures and appendices. The first section provides a detailed description of the porphyroblast microstructures in the contact aureole of the Mooselookmeguntic pluton. It uses foliation inflection/intersection axis measurements in garnet and staurolite porphyroblasts (FIAs) to show that without 3D measurements of these microstructures, it is impossible to accurately correlate deformation and metamorphism across a region. Sections B and C use EPMA dating of the monazite grains included in staurolite porphyroblasts to reveal longer tectono-metamorphic histories in Western Maine and the

Colorado Front Range than was previously believed. The last section integrates the results obtained from the previous chapters with thermobarometry and phase diagram modeling to constrain the PT evolution of the region under study. This is part of a larger research project in the Northern Appalachians undertaken by the Structural and Metamorphism Research Institute (SAMRI) at James Cook University. Shyam Ghimire, another PhD student in the SAMRI group at James Cook University is working on rocks collected from an area located about 3 kms south of the region under study. So far, he has obtained similar results to those presented in this thesis.

Porphyroblast inclusion trails provide a unique opportunity to examine how the small-scale geometries that form prior to porphyroblast growth begin to partition through the rock because these large crystals nucleate and/or grow at the initiation of deformation (Spiess and Bell, 1996). Bell (1981) suggested that porphyroblasts commonly nucleate and grow in sites of progressive coaxial shortening. Anastomosing zones of combined non-coaxial shortening and shearing develop around these zones and when they intensify and interact with the growing porphyroblasts, growth ceases. He further argues that growth does not recommence until a new deformation occurs at high angle to the earlier one allowing new growth to occur in porphyroblast strain shadows (e.g., Bell and Rubenach, 1983; Bell et al., 1986; Bell and Hayward, 1991).

If this is correct then porphyroblasts trap and preserve as inclusion trails microstructures that are destroyed in the matrix by the same event or during subsequent deformations. Therefore, examining the geometry of the inclusion trails in porphyroblasts and their relationship to the surrounding matrix should provide important information on the processes occurring early in the local deformation history of multiply deformed

metamorphic terranes and reveal a tectonic record that is much more complete than that preserved in the matrix (e.g. Cihan and Parsons, 2005; Rich, 2006). This thesis seeks to test this hypothesis.

Identification of porphyroblast micro-fabrics using conventional methods has been accomplished by many studies (e.g., Zwart, 1962; Vernon et al., 1993). Such methods usually provide a very simple history because, thin sections cut perpendicular to the matrix foliation reveal very little inclusion trail complexity (e.g., Cihan, 2004). Studies using the relatively new approaches described herein provide much more extensive deformation and metamorphic histories and show that deformation processes are much more complex than previously believed (e.g., Bell et al., 2004; Bell and Newman, 2006). Measuring FIAs (Bell et al., 1995) and the concept of "*reactivation of bedding during successively formed foliations*" (Bell et al., 2004) provide the backbone of this thesis. Measuring FIAs involves cutting 8 to 10 vertically-oriented thin sections per sample. Although this requires a lot of effort, it allows an order of magnitude more rock to be observed in 3-D. This approach proves to be vital for understanding how to integrate deformation and metamorphic processes, as their inter-relationship cannot be quantitatively accessed in any other way.

Through FIA analysis the same generation of porphyroblasts can be correlated across a region. FIAs form at high angle to the direction of main bulk shortening so that studying the orientation of the inclusion trails has regional-scale significance. EPMA dating of monazite grains included in staurolite porphyroblasts that contain one or a succession of different FIA trends allows the absolute timing of a specific deformation and metamorphic event to be accurately constrained. In this way mineral associations that

characterize a FIA event can be discerned and the PT conditions responsible for forming these mineral associations can be deducted.

Section A of the thesis is mainly meant as an introduction to the complex deformation and metamorphic history of the region under study as revealed by porphyroblast inclusion trails microstructures. The FIAs were measured in both garnet and staurolite porphyroblasts and their relative timing were established based on microstructural and textural relationships. The orientations of foliations preserved as inclusion trails in staurolite porphyroblasts were measured as pitches and plotted on stereo nets to obtain 3D orientations from which similar trends with FIAs were obtained. These data are discussed in terms of their significance for the regional deformation and metamorphic history as well as the effect of partitioning of deformation on porphyroblast microstructures and their relationship to the surrounding matrix.

Section B uses EPMA dating of monazite grains included in staurolite porphyroblasts to constrain the absolute timing of the development of the succession of FIAs. The results presented in this part of the thesis have an extraordinary impact on the regional tectono-metamorphic history by suggesting that tectonism and plutonism in the Northern Appalachian extended over a much larger period of time than previously believed. The implications for deformation, metamorphism, and plutonism are discussed.

Section C of the thesis provides an example from two spatially and temporally separated terranes, the Paleozoic West Central Maine and the Proterozoic Colorado Front Range, where multiple periods of staurolite growth occurred over a lengthy period of time.

The similarities between the two regions indicate that such processes may be common for most of the orogenic belts. My contribution to this section is 50% in both data collection and concepts.

Section D of the thesis combines the results obtained from the previous sections with phase diagram modeling and thermobarometry to infer PT-d-t paths in Western Maine. The computer software Thermocalc was used to model mineral stability fields for the mineral assemblages present in the contact aureole of the Mooselookmeguntic pluton. The effect of changing bulk composition on the phase diagram topology was also investigated.

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