Tectono-metamorphic evolution of Big Thompson Canyon region, Colorado Rocky Mountains, USA

Volume I

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CONTENT OF VOLUME 1

STATEMENT OF SOURCES

DECLARATION

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published and unpublished work of others has been acknowledged in the text and a list of references is given

Afroz Ahmad Shah

July 2010

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DECLARATION

I, the undersigned, the author of this thesis, declare that the electronic copy of this thesis provided to the James Cook University Library is an accurate copy of the print thesis submitted, within the limits of the technology available.

Afroz Ahmad Shah

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INTRODUCTION AND THESIS OUTLINE

The geologically continuous nature of relative plate motion, which drives orogenesis, versus the limited number of deformations preserved in the matrix of rocks, has always been an anomaly that requires explanation. Porphyroblast studies suggest that a large amount of orogenic history has been destroyed in the matrix and may reveal that deformation and metamorphism is continuous, although partitioned both spatially and temporally, for periods of a few 100 million years (e.g., Bell et al., 2004; Bell & Newman, 2006). Reactivation (shearing) of the bedding or compositional layering in successive deformations destroys previously developed foliations in the matrix. However, porphyroblast growth prior to reactivation generally preserves these foliations, plus the metamorphic history, from destruction. If the P-T and bulk composition conditions are suitable for porphyroblast growth, this history is generally trapped within porphyroblasts, which appear to grow during regional metamorphism only where the deformation occurs (e.g. Bell and Rubenach, 1983; Bell and Johnson, 1989; Bell and Hayward, 1991, Cihan 2004; Cihan and Parsons; 2005).

Foliation intersection axes preserved within porphyroblasts (FIAs) enable linkage of the structural and metamorphic histories from sample to regional scales through consistent changes in their trend from the core to median to rim (e.g., Bell et al., 1998, 1981). Significantly, regionally consistent successions of FIA trends reflect changes in the direction of bulk shortening, which must in turn reflect changes in the direction of relative plate motion. The period of time over which each FIA trend developed has been dated by electron microprobe and ion microprobe techniques using U-Th-Pb in monazite inclusions, correlated directly with shear sense from inclusion trail asymmetry, as well as with phases of porphyroblast growth.

Combining this data with the construction of P-T pseudosections (phase diagrams specific to a particular sample's bulk composition that provide a map of stable mineral assemblages in P-T space) and thermobarometric calculations using THERMOCALC allows P-T-t-d paths to be determined and correlated from sample to sample and region to region. Thus quantitative integration of metamorphism, structure and tectonics within an orogenic belt has become an exciting possibility. This contribution provides an example of such an integrated approach using microstructural, FIAs, thermodynamic modelling (MnNCKFMASH) and chemical relationships to investigate in detail the metamorphic and deformation processes and the progression in the distribution of various index mineral phases (garnet, staurolite, andalusite and cordierite). The Big Thompson Canyon region, Colorado Rocky Mountains, USA forms part of a Proterozoic orogenic belt in the southwestern United States and provides a classic example of a large high-T-low-P terrane and the problems associated with the tectonic interpretation of such a regime (e.g., Williams and Karlstrom, 1996). These rocks have been affected by strongly partitioned deformation and provide an ideal place for developing new concepts on the role of deformation partitioning in deformation, metamorphism and tectonism.

This thesis consists of four sections (A-D), with each written in the manner of papers for submission to journals, although it is not intended that section B be submitted in its present form. A part of section A has been published in the Acta Geologica Sinica and

Section C has been submitted to the *Precambrian research.* Section D has been submitted to the Journal of Geological Society of India and was co-authored by Dr. Ioan Sanislav and myself, and we both agree that conceptually, literally, and graphically we each contributed 50% to that paper. Volume I contains the paper text and Volume II contains the accompanying tables, figures, and appendices.

SECTION A

This section explains the FIA (foliation intersection/inflection axes preserved within porphyroblasts) technique and its application to all samples are used in this research. FIAs were measured in garnet, staurolite, andalusite and cordierite porphyroblasts preserving older foliations as inclusions trail microstructures. Their relative timing was established based on microstructural and textural relationships. A progression of FIAs trending successively NE-SW, E-W, SE-NW and NNE-SSW reveals four periods of staurolite and garnet growth and two growth phases each of cordierite and andalusite. Isograds associated with each of these FIAs shift progressively across the orogen. This migration took place relative to a heat source to the WNW. Early formed staurolite was altered to cordierite and andalusite during development of the last 2 of these FIA sets (trending SE-NW and NNE-SSW). The lack of relationship of these isograds to pluton boundaries to the north and south suggests that these igneous rocks were not the primary heat source for metamorphism. The youngest of these isograds lie sub-parallel to those mapped by previous workers

SECTION B

This part of the thesis involves the use of microstructural and FIA evidence to track down the overall prograde mineral succession in these metasediments. It suggests that garnet, staurolite, andalusite and cordierite porphyroblasts grew in an overall prograde path, where the growth of garnet was always followed by the formation of staurolite for each FIA. For the last 2 periods of FIA development the growth of staurolite was also followed by the development of andalusite and cordierite. Inclusions of earlier minerals within the younger phases support the porphyroblastic mineral sequence obtained through FIAs.

Thermodynamic modeling in the MnNCKFMASH system reveals that the episodic growth of these phases occurred over a similar bulk compositional range and PT path for each FIA in the succession. The intersection of Ca, Mn, and Fe isopleths in garnet cores for 3 samples, containing FIA set 1, set 2 and set 3, trending NE-SW, E-W and SE-NW respectively, indicate that these rocks never got above 4kbars throughout the Colorado Orogeny. They remained around the same depth until the onset of younger orogeny at ~1400 Ma, when the pressure decreased slightly as porphyroblasts formed with inclusion trails preserving FIA set 4 and trending NNE-SSW. A slightly clockwise P-T path occurred for both orogenies.

SECTION C

In this section in-situ EPMA (electron probe microanalysis) dating of monazite grains preserved as inclusions within foliations defining FIAs contained within garnet, staurolite, andalusite and cordierite porphyroblasts is described, interpreted and explained. Monazite grains contained within matrix foliations were also analysed and compared with the dates obtained from porphyroblasts where the FIAs were used to determine the relative age succession. This data have provided a chronology of ages for extended periods of deformation and metamorphism in the region. Garnet and staurolite formed episodically for a period of ~100 Ma during the Colorado orogeny, ceased and then recommenced ~300 million years later during the Berthoud Orogeny

SECTION D

This part of thesis compares two spatially and temporally separated terranes with similar histories of porphyroblast development and associated granite emplacement at similar levels in the crust. These areas are a Paleozoic portion of West Central Maine and the Proterozoic Colorado Front Range, where multiple periods of staurolite growth occurred over a lengthy period of time. The metastable preservation of early staurolite porphyroblasts through successive deformation and metamorphic events highlights the importance of deformation on porphyroblast nucleation and growth. These two areas show that the reactions involved in the formation of metamorphic minerals are episodic during prograde metamorphism, starting or stopping, as a function of deformation partitioning and strain localization. Accessory minerals such as monazite can be dated and their ages can be better integrated in the deformation and metamorphic history of a region when they are well constrained by microstructural measurements.The similarities between the two regions indicate that such processes may be common for most of the orogenic belts.

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