THE PALEOZOIC TECTONO-METAMORPHIC EVOLUTION OF THE CHARTERS TOWERS PROVINCE, NORTH QUEENSLAND, AUSTRALIA

Volume I

(Text)

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STATEMENT ON THE CONTRIBUTION OF OTHERS

Prof. T. H. Bell developed the technique central to this study. He initiated this project, spent many hours working with me on a dual microscope and edited all drafts.

Dr. I. V. Sanislav is co-author of section A of the thesis; he collected the two samples from Maine (USA) and helped with data collection and interpretation.

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CONTENT OF VOLUME I

THESIS ABSTRACT

The main objective of this thesis is to better understand the processes of growth and evolution of continental lithosphere using the example of the Charters Towers Province (North Queensland, Australia) part of the Tasman Orogenic System. This province contains E-W structural and pluton trends that differ in orientation from the N-S trends of the adjacent orogens of the Tasman Orogenic System. The long lasting and complex tectono-metamorphic history of this continental orogenic system is unraveled using a multidisciplinary approach that discriminates discrete events within a seemingly continuous evolution. This involves structural and microstructural investigations, the FIA (Foliation Inflexion/Intersection Axis preserved in porphyroblasts) measurement technique, monazite geochronology and the interpretation of geophysical imagery (aeromagnetic map and seismic section).

The rocks sampled from the Seventy Mile Range Group and the Charters Towers Metamorphics (South Charters Towers Province) consist of lower amphibolite grade pelites containing cordierite +/- andalusite porphyroblasts, which are typical mineral assemblages for low pressure-high temperature terrains. Both porphyroblastic phases are retrogressed into partial to complete micas rich pseudomorphs associated with the appearance of retrograde chlorite.

The first section of the thesis investigates the textural development of mica rich pseudomorphs after cordierite based on two examples: partial pseudomorphs from rocks near the Mooselookmeguntic pluton in western Maine (USA) and complete pseudomorphs from rocks near the Lolworth batholith in the southern Charters Towers Province (North Queensland, Australia). Both regions contain mica rich pseudomorphs after cordierite that show evidence of

progressive textural development under an active stress regime. The complete pseudomorphs of the Charters Towers Province consist of preferentially aligned or "randomly oriented" fine grained muscovite, chlorite, ± biotite. The partial pseudomorphs from Maine consist of preferentially aligned coarser grained muscovite and biotite. The preferred orientation of micas is parallel to the orientation of the inclusion trails. The micas grew preferentially along microcracks that developed in the same direction with the inclusion trails and moved progressively from the porphyroblasts margin towards the porphyroblasts core. At least three types of microcracks can be identified with two of them being relevant for the replacement process. The first one formed by direct replacement of quartz inclusions by plagioclase and volume expansion and the second one was caused by high strain rates. A new image analysis based method was developed for mineral amount calculation that allows the production of mineral distribution maps within sections of metamorphic rocks from X-Ray elemental distribution maps. Combined with electron microprobe analyses of the minerals from the pseudomorphs and the surrounding matrix, it is interpreted that the maximum pressures experienced by the rocks from the Charters Towers Province were around 3 kbars and the maximum temperature did not exceed 600°C, most probably lying near the 550°C isotherm. Temperatures obtained via the Ti-in biotite thermometer may reflect retrograde conditions rather than peak conditions. This strongly chemical equilibration dependant thermometer indicates systematically higher temperatures for biotite from the matrix than from the pseudomorphs indicating that equilibration of biotites in the matrix occurred prior to pseudomorphism. This implies that the metamorphic reactions are localized to the volume occupied by the cordierite and the material exchange with the matrix is limited.

The second section of the thesis investigates the anomalous E-W structural and igneous trends in the Charters Towers Province within the overall N-S trending Tasman Orogen. These

resulted from a sequence of N-S shortening events. A succession of ~E-W trending FIAs (Foliation Intersection/Inflexion Axis preserved within porphyroblasts) dated at 474.7 ± 7.2, 413 ± 13 and 381.1 ± 8.1 Ma correspond with adjacent granite crystallization ages and E-W trending FIA ages in the Greenvale Province to the NW. The magnetic anomaly map of Australia reveals that this E-W trending portion of the Tasman orogen links with and truncates several earlier formed orogens. The E-W trend of the Charters Towers Province resulted from overprinting of the Tasman Orogen by the Alice Springs Orogeny resolving the E-W pluton shape and distribution of Cambrian to Devonian magmatic activity plus the truncational nature of aeromagnetic data from Central Australia to the East coast.

In the third section of the thesis, strong non-coaxial deformation in the Seventy Mile Range Group in the south of the Charters Towers Province is revealed by the dominance of one inclusion trail asymmetry within porphyroblasts during successive FIA forming events. This asymmetry indicates top to the north thrusting and corresponds with south dipping thrusts on the seismic profile 07GA-GC01 through the Seventy Mile Range Group. Similar thrusts, all of which sole into the Moho, occur across the whole of the Charters Towers Province except where it has been intruded by the Ravenswood batholith. The competency of this coarse feldspar batholith caused partitioning of thrusting deformation around it and this is confirmed by the coaxial character of the inclusion trail geometries present within porphyroblasts within Charters Towers Metamorphics surrounded by the Ravenswood batholith. Long-lived non-coaxial deformation in the Seventy Mile Range Group eventually resulted in thrust sheets being emplaced well to the north of the batholith with a window through a schistose thrust sheet within the Argentine Metamorphics exposing Devonian sediments below.

The last section of the thesis concludes that the tectonic evolution of the Charters Towers Province (northeastern Australia) in the Paleozoic resulted from the interaction between N-S and E-W bulk shortening. The origin of N-S shortening results from horizontal forces acting at the plate boundary that are possibly related to ridge-push effects due to the opening of the Paleotethys at ~450 Ma. This produced the ~450 to 300 Ma intracontinental E-W trending Alice Springs Orogen in central Australia whose effects propagated eastward to create the E-W trending Charters Towers Province. E-W shortening is interpreted to result from the long-lived west dipping subduction along the eastern margin of Australia, which was part of Gondwana at the time. FIA data reveals several discrete deformation events of interspersed ~N-S and ~E-W shortening directions. The FIA ages were obtained through in-situ monazite dating and show N-S shortening events at ~475 Ma and ~415 Ma, followed by ~E-W shortening at ~400 Ma and N-S shortening at ~380 Ma in the Charters Towers Province. The magnetic anomaly map of Australia, used to locate the lateral extensions of shear zones and domain boundaries hidden by overlying sedimentary successions, allowed the linking of deformation structures from central to northeastern Australia. Compressional orogenesis in the Charters Towers Province resulted in sinistral strike-slip extrusion of the Thomson Orogen to the east that was possibly associated with periods of slab roll-back.

Keywords: Tasman Orogenic System, Thomson Orogen, Charters Towers Province, Alice Springs orogeny, pseudomorphs, FIAs, inclusion trail asymmetry, monazite dating, aeromagnetic truncations, thrust window, strike-slip faults, extrusion tectonics.

INTRODUCTION AND THESIS OUTLINE

This thesis investigates the tectono-metamorphic evolution of the Charters Towers Province, North Queensland, Australia. This province is part of the Tasman Orogenic System that was accreted against the Precambrian crystalline basement of Australia to the west during the Paleozoic resulting in a mainly N-S trending belt (Murray and Kirkegaard, 1978; Scheibner, 1978a, b, 1986; Coney et al., 1990; Gray and Foster, 2004; Glen, 2005). Consequently, the E-W structural and pluton trends of the Charters Towers Province indicate a complex tectonic evolution of the province relative to its surroundings. Contemporaneous with the development of the Tasman Orogen, a long-lived intracontinental deformation occurred in central Australia resulting in the E-W trending Alice Springs Orogen (Collins and Teyssier, 1989; Mawby et al., 1999; Ballèvre et al., 2000). Difficulties in reconciling the Paleozoic deformation of central and eastern Australia are due to two main factors (Betts et al., 2002). Firstly, the inferred shortening directions are orthogonal; south directed thrusting in the intracontinental E-W trending Alice Springs Orogen and E-W compression of the Tasman Orogenic System in eastern Australia. Secondly, geochronological data only allows for broad temporal correlations between the regions.

From the Tasman Orogenic System to central Australia only one-third of the basement rocks are not covered by younger flat lying units. Access to information on these rocks is largely provided by gravity and magnetic data and by deep drill holes through this cover (Wellman, 1988, 1992, 1995; Draper, 2006). The magnetic anomaly map of Australia at a continental scale (Milligan and Franklin, 2004) provides in many cases the only mean for defining boundaries between structural domains distinguished by sub-parallel magnetic trends that reveal tectonic structures within deformed portions of the upper crust.

Work done over the past three decades on folds and foliation development, crenulation and decrenulation due to reactivation of compositional layering, and porphyroblast nucleation and growth have led to a comprehensive understanding of micro- and macro-fabric development during deformation and metamorphism and their significance for orogen evolution. Bell et al. (1986) suggested that porphyroblast nucleation and growth occurs in zones of progressive coaxial shortening. Anastomosing zones of combined shortening and shearing develop around these coaxial zones. With increase in strain they intensify, interact with the margin of the growing porphyroblast, and cause growth to cease. Porphyroblast growth occurs early during crenulation development and the curvature of inclusion trails results from an overprinting deformation with the asymmetry of the curvature resulting from the inflexion of an earlier foliation affected by a younger event (Bell and Rubenach, 1983; Bell et al., 1986). Porphyroblast growth does not resume until crenulations develop anew at high angle to the earlier ones (e.g. Bell and Rubenach, 1983; Bell et al., 1986; Bell and Hayward, 1991; Spiess and Bell, 1996; Bell et al., 2003).

Inclusion trails preserved within porphyroblasts represent microstructures formed prior to or synchronous with porphyroblast nucleation and growth that are commonly obliterated from the matrix by subsequent deformation and associated shear parallel to the compositional layering (Bell, 1986; Ham and Bell, 2004). The quantitative measurement of foliation intersection/inflexion axes preserved within porphyroblasts (FIAs) provides access to the lengthy deformation history of a region (Bell et al., 1995; Bell et al., 1998; Bell et al., 2003). A FIA represents the orientation of the axis of curvature of a foliation affected by an overprinting event or the intersection lineation of two foliations preserved as inclusion trails within porphyroblasts. The FIA appears to form near orthogonal to the direction of the main bulk shortening and constitutes a powerful kinematic indicator for early deformation events subsequently erased from the matrix. EPMA dating of monazite grains preserved as inclusions within foliations defining the FIAs enables the determination of absolute timing of the successive FIA events.

The thesis consists of four sections, each intended for publication in international journals. The sections are ordered such that they progress in a logical manner. Volume I contains the text and reference list, while Volume II contains figures, tables and appendices.

Section A of the thesis investigates the textural development of mica rich pseudomorphs after cordierite. Due to the relatively high stability and occurrence of cordierite in a variety of rocks and a range of PT conditions, this mineral plays a significant role in our understanding of processes that take place during metamorphism. The mechanism investigated herein comprises the interrelated processes of combined fluid rock interactions, PT conditions and deformation. The porphyroblastic rocks sampled in the Charters Towers Province contain an assemblage of andalusite and cordierite porphyroblasts typical of low pressure high temperature terrains. Cordierite porphyroblasts are commonly fully retrograded to pseudomorphs of a fine- to medium-grained phyllosilicate assemblage. Understanding the replacement mechanism was of critical importance with regards to its effects on inclusion trails geometries. Rocks from Maine (USA) where partial pseudomorphs after cordierite occur, but at a higher metamorphic grade, were used to investigate the progressive replacement of cordierite. X-ray maps, image analysis, electron microprobe analyses of the minerals from the pseudomorphs and the surrounding matrix were used to quantify mineral modes, mineral distribution and the PT conditions.

Section B focuses on the development of the E-W structural grain of the Charters Towers Province. This section uses the magnetic anomaly map of Australia, structural trends relationships between adjacent provinces, granite ages from deep drill holes through cover and the ~E-W trending FIAs recorded in the Charters Towers and Greenvale provinces. New FIA ages were obtained in the Charters Towers Province using EPMA dating of monazite grains preserved as inclusion within foliations defining the ~E-W FIAs. These data were combined to investigate the linking of deformations between central and eastern Australia.

Section C uses FIA measurements, the interpreted succession of FIA sets and systematically recorded asymmetries of inclusion trail curvatures preserved in porphyroblasts for each FIA set. The inclusion trail asymmetries were observed in vertical sections cut near orthogonal to the trend of the contained FIA. This allows determination of successive shortening directions and shear senses that affected the region at specific times during the evolution of the orogen during microstructure development prior to or synchronous with porphyroblast nucleation and growth. This method provides additional information on early deformations compared to the conventional approach of only using thin sections cut perpendicular to the matrix foliation and parallel or perpendicular to the stretching lineation. Sections parallel to the stretching lineation only allow determination of shear senses for the latest deformation events that affected a region. The example presented herein proves that it is possible to identify nappe or thrust sheet emplacement in multiply deformed terrains where recognition of such structures is commonly hindered by subsequent deformation events.

Section D integrates all data and interpretations obtained in the previous sections plus the interpretation of the remaining FIA sets, additional EPMA monazite dating, pluton spatial and temporal distribution and aeromagnetic trends in the Charters Towers Province and its surroundings. An attempt is made to reconcile the Paleozoic deformation of central and eastern Australia and a tectonic evolution model is proposed.

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