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Metamorphic styles in young and ancient orogenic belts

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Metamorphic styles in young and ancient orogenic belts: introduction

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This Special Issue brings together 12 of the papers presented at an IGCP field conference 'Metamorphic Styles in Young and Ancient Orogenic Belts' held at The University of Calgary in August 1990. The conference was the final meeting of IGCP Project 235 'Metamorphism and Geodynamics' and the first meeting of the successor Project 304 'Lower Crustal Processes'.

FIELD TRIPS

Pre-meeting and post-meeting field trips complemented the theme of the meeting. The pre-meeting field trip first focused on the 'ancient', a geological transect from Kingston to Sudbury, Ontario, across the SW Grenville Province (1.3–1.0 Ga), in which deep crustal metamorphic and geodynamic processes were examined (Davidson *et al.*, 1990). One of the themes of the trip was the examination of different granulite-forming processes: dry metamorphism, e.g. coronitic metagabbros; dehydration melting, e.g. orthopyroxene-bearing metapelitic migmatites; and infiltration metasomatism, e.g. net-veined metagabbroic granulite. This topic generated considerable discussion throughout the trip: there was uncertainty whether outcrop-scale transitions between amphibolite and granulite represented prograde or retrograde processes; there was disagreement over the way in which fluids had escaped from outcrops in which most agreed that dehydration-melting had proceeded; and there was disagreement over the origin of quartzofeldspathic segregations in charnockitic gneiss. The influence of fluid infiltration in outcrops at greenschist and amphibolite facies was also openly debated, both from textural grounds and from phase equilibria constraints.

Of special interest were the high strain zones separating the lithotectonic domains of the Grenville Province, in which a rich variety of kinematic indicators is preserved. A recurring structural debate centred on the identification of mylonites, and gauging their relative abundance in the ubiquitous highly strained rocks along the field trip route. The trip concluded with a series of stops across the Grenville front, a major crustal tectonic boundary, in which one goes from highly strained high-P granulite facies rocks into relatively undeformed greenschist facies rocks over the space of a few kilometres.

The post-meeting field trip focused on the 'young', a transect from Calgary, Alberta, to Sicamous, B.C., across the transition from the foreland thrust belt to the metamorphic core zone of the SE Canadian Cordillera (Ghent *et al.*, 1990). The trip emphasized the change in metamorphic grade and structural style of a package of Late Precambrian clastic rocks. These rocks were examined from the chlorite zone in the Rockies to the sillimanite zone south of Mica Creek, British Columbia, in the Omineca Crystalline Belt.

The participants also examined parts of the 'Shuswap Complex', a series of metamorphic core complexes within the Omineca Belt. The only known occurrence in the Omineca Belt of granulite facies assemblages in metabasite boudins was examined. The relationship of metamorphism to the large-scale structure was debated.

One of the features of the trip was the widespread occurrence of the Al-silicate polymorphs, with several clear examples of replacement textures. This led to spirited discussion regarding the metamorphic history. On the last day, we examined structures related to extensional tectonics and mylonitic rocks near the Revelstoke Dam. The relationship of these features to the earlier structure and the timing of the exhumation of the metamorphic core complexes was discussed.

PAPERS

The papers in this Special Issue reflect the main themes of the meeting in Calgary: the effects of fluids, reaction relationships, P–T–t paths, and thermotectonic styles. Three papers are concerned with advective fluid movement in medium- to high-grade metamorphic rocks. **Newton** documents world-wide occurrences of diffuse charnockitic alteration (arrested orthopyroxene formation in biotite- and amphibole-bearing rocks), and ascribes many of these occurrences to infiltration of a CO_2-rich fluid. He notes that in some situations, partial melting may have been triggered by volatile infiltration. He argues that in some granulite terranes, fluid infiltration may have been a significant causative agent of granulite facies metamorphism, while in others it may have been at best a local phenomenon.

Jackson & Santosh use silicate phase equilibria, variations in modal graphite and stable isotopes to document a 30-m-wide zone of infiltration-driven sub-solidus dehydration of amphibolite facies gneiss to granulite facies charnockite, near Nuliyam, India; the source of the CO_2 is ascribed to an adjacent calc-silicate layer. Observed reaction and carbon isotopic fronts are inconsistent with an equilibrium continuum mechanical theory of advective fluid transport, suggesting that local fluid–rock disequilibrium prevailed during the infiltration episode.

This Special Issue is a contribution to IGCP Projects 235 and 304 (Metamorphism and Geodynamics, Lower Crustal Processes).

Yardley & Bottrell studied quartz veins in the upper amphibolite facies rocks of Connemara, Ireland. They argue that the absence of significant metasomatic effects in the wall rocks and the matching of oxygen isotopic composition between the veins and the wall rocks suggest local metamorphic segregation processes without through-flowing externally derived fluids. Fracturing and local pumping of fluid were important processes in the development of the quartz veins. Isotope results demonstrate that no large-scale fluid convection cells were developed during metamorphism.

Six papers document the tectonothermal evolution of structural/metamorphic terranes ranging in age from Archaean to Tertiary. **Mogk** investigated the structural and metamorphic evolution of Archaean migmatitic tonalite–trondjhemite gneisses from the N. Gallatin range, SW Montana. He argues for an intimate interplay of ductile shearing, hydrous vapour influx and vapour-consuming melting, which chemically and mechanically reworked the entire volume of gneiss. He suggests that such a process may be an important agent of crustal differentiation.

Jamieson *et al.* interpret part of the Central Gneiss Belt of the Grenville Province, Canada, as containing a major decollement. The footwall of the decollement contains relict pre-Grenville granulite assemblages, while the hangingwall contains lithological packages that have experienced only Grenville metamorphism. Two distinct stages of Grenville metamorphism can be recognized. The data suggest that early convergence was followed by a period of crustal thickening in an orogenic core south of the study area, with further advance to the north-west during and after the waning stages of this deformation.

Rubenach combines microstructural and geochronological data with phase equilibrium arguments to interpret an anticlockwise P–T–t path for an area within the Proterozoic Mount Isa Inlier, Australia. The thermal gradient during a peak metamorphism may have been $80^\circ C\,km^{-1}$ or more, suggesting a now-hidden magmatic heat source.

Henry & Dokka use detailed textural relations and geothermobarometry to document in detail the complex P–T–t history of the Mesozoic Waterman metamorphic complex, Mojave Desert, California, a metamorphic core complex exposed during Miocene extension. The unusual P–T–t path includes high-grade segments suggestive of isobaric cooling and isothermal decompression. Combined with structural data, the P–T–t path is interpreted to record collision, thrusting and two periods of regional extensional.

Osanai *et al.* investigated Tertiary granulites from the base of the Main Zone of the Hidaka belt, Japan, interpreted to be an imbricate stack of island-arc material. Based on geothermobarometry and melting experiments, they ascribe the widespread development of orthopyroxene-bearing leucosomes in the granulites to anatexis.

Inger & Harris studied an apparent inversion of metamorphic isograds in the High Himalayan Crystalline sequence in north-central Nepal. They suggest that the inversion is a result of polyphase metamorphism. A mechanically coherent section of the crust, metamorphosed under Barrovian conditions (M1), was thrust over lower grade units. A second heating event (M2) overprinted the upper part of the thrust sheet, resulting in sillimanite-zone conditions and anatexis of metapelites. The cause of the selective heating (M2) is problematic, but may be due to normal fault movement which caused blanketing of metapelites of high heat productivity with low-grade sediments of low thermal conductivity.

Three papers examine regional-scale tectonometamorphic evolution. **Perchuk *et al.*** present the results of numerical simulations which support the notion that P–T–t paths of metamorphic complexes arise from single-stage convective processes in the lithosphere. Two models are considered: thermally activated multi-layered sequences and rising diapirs.

Armstrong *et al.* present a tectonothermal model for the evolution of the classic Acadian (early–mid Palaeozoic) orogen in central and western New England, which they subdivide into an eastern (earlier) and western (later) belt based on contrasting ages, metamorphic field gradients and P–T histories. In the eastern belt, they argue that sedimentation and the rise of plutons along a magmatic arc resulted in high-T, low-P metamorphism and crustal anatexis. Upward melt migration, accompanied by E–W shortening, resulted in mechanical conditions favourable for tectonic thickening by nappe formation to the west, resulting in lower-T, higher-P metamorphism.

Brew *et al.* review the occurrence of 17 distinct metamorphic belts within the cordilleran orogen in SE Alaska. They suggest that these rocks comprise three major metamorphic elements and that the complex metamorphic–plutonic history was related to Late Jurassic to Late Cretaceous collisions of terranes and subduction of Pacific oceanic plates.

SUMMARY

Enormous progress has been made in our understanding of tectonometamorphism over the last decade by the use of geochronological data, structural features, petrological data, different approaches to the derivation and application of phase equilibria, and thermal modelling. As the final event of IGCP Project 235 and the first event of the successor Project 304, this meeting and collection of papers effects a transition from consideration of tectonometamorphic processes in the middle–upper parts of orogenic belts to the deeper root zones. Given the present debate on several aspects of deep crustal metamorphism, the vitality of IGCP Project 304 is ensured.

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