METAMORPHIC STUDIES IN THE VREDEFORT DOME, SOUTH AFRICA

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Statement of original contribution

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg, South Africa. It has not been submitted before for any degree or examination in any other University.

Signed this 8th day of June 2010

Paula Ogilvie

Abstract

Metasedimentary granulites in the core of the Vredefort Dome present textural and chemical evidence for three discrete metamorphic events. These include a peak Archaean anatectic event (M_1), shock metamorphism (M_2) with impact at 2.02 Ga and post-shock metamorphism (M_3) of the target rocks related to Dome formation and non-adiabatic loading of the crust.

Regional granulite facies metamorphism (M_1) occurred between 3.10 Ga and 3.08 Ga with tectonomagmatic thickening of the crust attributable to easterly- to northeasterly-directed subduction of an oceanic slab beneath the Kaapvaal craton. Phase equilibria modelling in THERMOCALC of highly restitic pelitic granulites constrains peak conditions of M_1 metamorphism at 870 - 885 ºC and 7.1 - 7.7 kbar. Slightly lower peak conditions of 858 °C and 7.1 kbar were obtained for a more melt-rich granulite, reflecting back-reaction with a melt on the suprasolidus retrograde path. The prograde up-pressure trajectory is dominated by heating from 6.5 kbar, 700 °C to 7.5 kbar, 850 °C. Phase equilibria constraints on the prograde and suprasolidus retrograde evolution are consistent with a clockwise Archaean *P-T* path for the M_1 event.

Overprinting the M_1 peak assemblage are shock-induced, extreme disequilibrium deformation features (irregular shock fractures, planar fractures, planar deformation features, isotropization and shock melting) that formed instantaneously during meteorite impact at 2.02 Ga (M_2). Reconstruction of the shock pressure and post-shock temperature distribution across the central core of the Vredefort Dome from observed shock effects in component phases from the pelitic granulites required an experimental study to constrain shock effects in an analogous, complex, polymineralic, pelitic granulite from the Etivé aureole, with a significant proportion of hydrous and ferromagnesian minerals. Shock experiments were performed at 12.5, 25, 34, 40 and 56 GPa at 25 °C, and at 18 and 25 GPa at 400 °C to investigate the roles of both increasing shock pressure and pre-shock temperature on shock deformation features in major minerals. Both the shock experiments and Vredefort granulites are characterised by heterogeneous distribution of shock effects in minerals on intragranular and intergranular scales. Shock heterogeneity compromises estimates of absolute shock pressures based exclusively on observed shock effects in minerals. Independent constraints on shock pressures are obtained from post-shock metamorphic conditions and range from > 35 GPa to > 40 GPa at 8 and 5 km from the centre of the Dome, respectively.

The Vredefort granulites underwent unusually rapid and highly variable M_3 heating, exhumation and cooling associated with the 2.02 Ga meteorite impact event. The short-lived nature of the thermal event and restitic bulk rock compositions owing to melt loss during the Archaean M_1 event, led to diffusion-controlled reaction and the growth of coronas around garnet. Coronas display a strongly sectoral development indicative of highly localized compositional domains. Grain size, sectoral complexity and thickness of coronas all increase toward the centre of the Dome, indicating strong temperature control on the extent of reaction. This sectoral complexity is unique to Vredefort coronas compared to coronas reported from regional and contact metamorphic terranes and affords the opportunity to evaluate controls on extent of corona development and degree of equilibration. Minimum peak M_3 temperatures were 980 °C at 2.5 – 3.0 kbar, between 8 and 5 km from the centre of the Dome.

Open-system diffusion and phase equilibria modelling of the Vredefort coronas has established a relationship between equilibration in granulites at the micrometre-scale as a function of temperature and melt fertility of the corona bulk composition. Higher melt modes and solidus depression in fertile corona bulk compositions enhance component diffusion and equalization of chemical potential gradients throughout the equilibration volume. Coronas are characterized by non-linear open-system metasomatic exchange of components with adjacent domains. Selective and variable open-system metasomatic exchange of components with the matrix or with contiguous domains is required to reproduce observed mineral modes and compositions. Reaction may be induced in chemically inert corona domains through open-system diffusive communication with a hydrous matrix, thereby fluxing the solidus and elevating melt modes. A better understanding of the textural and compositional evolution of coronas requires a shift from closed-system or linear phase equilibria modelling to non-linear, open-system modelling.

Dedication

This thesis is dedicated to my parents, Colin and Edna, and my brother and sister, Colin and Adrienne, for their endless support and encouragement.

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