Inefficient high-temperature metamorphism in orthogneiss

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ABSTRACT

A novel method utilizing crystallographic orientation and mineral chemistry data, based on large-scale electron backscatter diffraction (EBSD) and microbeam analysis, quantifies the proportion of relict igneous and neoblastic minerals forming variably deformed high-grade orthogneiss. The Cretaceous orthogneiss from Fiordland, New Zealand, comprises intermediate omphacite granulite interlayered with basic eclogite, which was metamorphosed and deformed at \( T \approx 850 ^\circ C \) and \( P = 1.8 \) GPa after protolith cooling. Detailed mapping of microstructural and physiochemical relations in two strain profiles through subtly distinct intermediate protoliths indicates that up to 32% of the orthogneiss mineralogy is igneous, with the remainder being metamorphic. Domains dominated by igneous minerals occur preferentially in strain shadows to eclogite pods. Distinct metamorphic stages can be identified by texture and chemistry and were at least partially controlled by strain magnitude. At the grain-scale, the coupling of metamorphism and crystal plastic deformation appears to have permitted efficient transformation of an originally igneous assemblage. The effective distinction between igneous and metamorphic paragenesis and their links to deformation history enables greater clarity in interpretations of the makeup of the crust and their causal influence on lithospheric scale processes.

Keywords: Neoblasts, EBSD, recrystallization, strain, tectonometamorphism, microstructure; Understanding of Reaction and Deformation Microstructures

INTRODUCTION

It is generally considered that elevated temperature conditions in the Earth’s crust (e.g., \( > 750 ^\circ C \)) are accompanied by widespread metamorphic equilibration because of elemental diffusion distances being comparable to or larger than the grain scale (Powell et al. 2005). Typically, metamorphic transformation is aided by pervasive deformation and the abundance of fluid (\( H_2O \) or melt: Štípská and Powell 2005; Powell et al. 2005). However, the persistence of high proportions of metastable minerals in orthogneiss exhumed from the lower crust is common (e.g., Austrheim et al. 1997; Štípská and Powell 2005; Racek et al. 2008). In circumstances involving inhibited metamorphism, parts of a given rock can be incompletely equilibrated (Vermor et al. 2008, 2012). The efficiency and scale of metamorphic equilibration must be queried in the context of results from analog experiments and mineral equilibria modeling to provide a robust understanding of the inferred petrogenesis (Powell et al. 2005; Štípská and Powell 2005). In turn, mineral chemistry and texture can be used to recover dynamic changes in extrinsic conditions that can be extrapolated to make geodynamic inferences (Marmo et al. 2002; Chapman et al. 2017).

In circumstances of inefficient metamorphism, sites of mineral reaction can be highly localized (e.g., Austrheim et al. 1997; Jamtveit et al. 2000) and can contribute to the partitioning of strain during deformation (Williams et al. 2014). A dynamic feedback between reaction kinetics and recrystallization mechanisms can accentuate reaction localization and mechanical differentiation (Yund and Tullis 1991; Stünitz 1998; Piazolo et al. 2016). Most studies of inhibited metamorphism focus on linking mineralogical change to brittle failure and/or fluid ingress (e.g., Jamtveit et al. 2000); there are few studies that assess the role of dynamic recrystallization during ductile deformation (e.g., Svahnberg and Piazolo 2010; Satsukawa et al. 2015). Changes in mineralogy have a direct bearing on the rheology and density of the lithosphere (Jackson et al. 2004; Bürgmann and Dresen 2008; Chapman et al. 2017). It is commonly assumed in the application of geodynamic models that metamorphism in the lower crust is highly efficient, yet this is an over simplification. Inefficient metamorphism is commonly associated with low heat- and/or fluid-flux environments, as occurs in cratons, but can also occur in orogenic settings due to changes in key extrinsic variables (Štípská and Powell 2005; Racek et al. 2008; Daczko et al. 2009). There is a need to establish a method to calculate the proportions of igneous material in partially metamorphosed and deformed granitoids from such settings.

In this paper, we quantify the proportions of igneous and metamorphic minerals in a case study of rocks that show partial to complete metamorphic transformation at high-\( T \) and high-\( P \) conditions (\( T \approx 850 ^\circ C \) and \( P = 1.8 \) GPa). We use unique exposures of rocks exhumed from lower crustal conditions in Fiordland, New Zealand, that preserve composite layered plutons, patchily deformed and transformed to granulite and eclogite (De Paoli et al. 2009, 2012). Metamorphism and deformation occurred immediately after, and plausibly concurrently with, the high-pressure emplacement of the plutons, but was spatially restricted. This example conflicts with most of the generalizations of lower crust