Forward modeling of the effects of mixed volatile reaction, volume diffusion, and formation of submicroscopic exsolution lamellae on calcite-dolomite thermometry

THOMAS MÜLLER,1,* LUKAS P. BAUMGARTNER,1 C. TOM FOSTER JR,2 AND GREGORY T. ROSELLE3

1Institute of Mineralogy and Geochemistry, University of Lausanne, CH-1015 Lausanne, Switzerland
2Department of Geosciences, University of Iowa, Iowa City, Iowa 52242, U.S.A.
3Sandia National Laboratories Carlsbad Programs Group, Carlsbad, New Mexico 88220, U.S.A.

ABSTRACT

This paper reports the results of several thousand analyses of the Mg content of calcite from 31 samples from the Ubehebe Peak contact aureole, Death Valley, California. All data reported are from metamorphic calcite formed during mixed volatile-mineral reactions in which dolomite remained in the rock. The Mg content generally increases toward the intrusive contact and bend with increasing temperature, but it varies strongly. Indeed, probability distributions for each sample are near Gaussian, possess a relatively small skewness (–1.72 to 3.32), and a variance that is a multiple of the estimated measuring uncertainty. These findings complicate direct application of the Mg content in calcite for use as an accurate thermometer.

The purpose of the study presented in the second part of the paper is to explore the significance of these systematic variations of Mg composition of calcite to aid the interpretation of contact metamorphic temperatures recorded in carbonates. We developed forward models to evaluate the effect of growth zoning, volume diffusion, and the formation of submicroscopic exsolution lamellae (<1 µm) on the measured Mg distribution in individual calcite crystals and compared the modeling results to the field data. Modeled Mg distributions were transformed into histograms by taking into account intersection probabilities and random microprobe analyses. Modeling results reveal that the original prograde Mg zoning in calcite crystal will be reset if the calcite crystal is assumed to grow slowly along a prograde path. Original low-Mg compositions can only be preserved if the entire grain forms over a small temperature interval, as can be expected for infiltration-driven mineral reactions. It is shown that all three mechanisms combined give an adequate model for the Mg-content data. We demonstrate that Mg distributions in calcite grains of the Ubehebe Peak contact aureole are the consequence of rapid crystal growth in combination with diffusion and exsolution.

Keywords: Calcite-dolomite thermometry, contact metamorphism, Ubehebe Peak, mineral growth, fluid infiltration

INTRODUCTION

Calcite-dolomite thermometry is commonly used to estimate peak temperatures in metamorphic carbonates. It is based on the temperature dependence of Mg exchange between calcite and dolomite, which has been experimentally calibrated (Goldsmith and Heard 1961; Powell et al. 1984; Anovitz et al. 1987). The principles and application of solvus thermometry were thoroughly reviewed by Essene (1983). Successful applications (Holness et al. 1991; Masch and Heuss-Abichler 1991; Cook and Bowman 1994; Letargo et al. 1995; Ferry 1996a) found temperatures from calcite-dolomite pairs in agreement with those obtained for silicate-carbonate equilibria. These studies concluded that the calcite-dolomite thermometer recorded peak metamorphic conditions. Rathmell et al. (1999) compared garnet-biotite, calcite-graphite, and calcite-dolomite thermometry in the Grenville Orogen in Canada. Although calcite-dolomite pairs yielded lower temperatures in comparison with the other two thermometers, resulting temperatures agreed quite well, if care was taken to use only calcite grains with no visible dolomite exsolution.

Maximum temperature-distance profiles obtained from calcite-dolomite thermometry in contact metamorphic terranes are mostly consistent with the spatial distribution of prograde metamorphic reactions given by equilibrium phase diagrams (Cook and Bowman 1994; Ferry 1996a; Roselle 1997). However, samples at similar distances from a pluton (Fig. 1) commonly exhibit differences in calculated temperatures of up to several hundred degrees (Cook and Bowman 1994; Roselle 1997; Ferry 2001), although they should have experienced the same temperature. This problem becomes more puzzling when one looks at how the temperatures were obtained. Typically a large number of microprobe analyses on different calcites are obtained from a single thin section. Figure 2 shows histograms of measured data that exhibit large variations in $X_{Mg}$, which indicate a range of up to 200 °C within a single sample. Furthermore, no simple concentric zoning patterns are observed within single grains. As a result, the interpretation of such data and thus the determination