Electron-microprobe age mapping of monazite

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ABSTRACT

High resolution X-ray maps of Th, U, Pb, and Y in monazite can be used to construct age maps, which reveal the continuous spatial distribution of ages in a single grain of monazite. The age mapping algorithm and three examples are presented to illustrate the capabilities and applications of this mapping technique, the insights it can provide into monazite geochronology in general, and its limitations compared to electron microprobe (EMP) quantitative dating and other in-situ geochronologic techniques.

Age maps offer critical information for unraveling metamorphic and tectonic histories and for interpreting results from other geochronologic techniques, and they are a valuable aid for rigorously locating in-situ analytical points. Age mapping also can be used to better understand the behavior of the U-Th-Pb system in monazite during metamorphism, deformation, and fluid-circulation events. Age maps presented in this paper reveal unsuspected age heterogeneities on the micrometer scale, like a now-healed fracture not visible in back-scattered electron (BSE) images or young domains less than 5 μm in width located inside an older core. In both cases, using age maps as a template for locating in-situ analysis points will minimize the peril of age mixing and erroneous geological interpretations.

In addition to providing critical information for illustrating and interpreting the history of complex polygenetic monazite, age mapping may ultimately lead to a better understanding of the processes involved with monazite growth and recrystallization, and thus, even more powerful applications of the monazite geochronometer.

The AgeMap program is available in a Windows version and can be downloaded from the internet at the following address: http://www.geo.umass.edu/probe/agemap.

INTRODUCTION

New analytical capabilities and operational software of modern electron microprobes have led to a broad array of new research applications in petrology, structural geology, and tectonics. Three of the most fundamental research directions include X-ray compositional mapping (Spear and Kohn 1996; Williams et al. 1999; Williams et al. 2001), trace-element analysis (Fialin et al. 1999; Chernoff and Carlson 1999; Jercinovic and Williams, this volume), and Th-U-Pb monazite geochronology (Montel et al. 1996; Cocherie et al. 1998; Crowley and Ghent 1999; Williams and Jercinovic 2002). Qualitative X-ray maps of garnet or plagioclase are now extensively used to complement conventional metamorphic analysis. For instance, imaging of compositional zoning is used as a monitor of mineral growth or consumption, or to better understand diffusion processes and element partitioning (Pyle and Spear 1999; Spear and Daniel 2001). Trace-element analyses and trace-element maps have been used to enhance metamorphic studies, especially when major-element compositions have been modified by diffusion or alteration (Chernoff and Carlson 1999). Finally and most recently, electron microprobe geochronologic studies have demonstrated a potential to unravel complex polyphase (metamorphic and structural) histories via the in-situ nature and high spatial resolution of the temporal data (e.g., Paquette et al. 2003).

Williams et al. (1999) combined these three techniques to construct “age maps” of monazite, which reveal the continuous spatial distribution of ages in a single monazite grain. The technique highlights the geometry and distribution of age domains at the micrometer scale, and it allows monazite ages to be placed into petrologic or structural context within the tectonic history. Isotopic in-situ dating techniques with a better analytical precision than EMP, such as SIMS or LA-ICPMS, may ultimately be used to characterize the isotopic age of mapped domains, but EMP analysis remains the only technique that can provide this two dimensional image of age distribution. This tool offers critical information for unraveling metamorphic and tectonic histories, for interpreting results from other geochronologic techniques, and for better understanding the behavior of the U-Th-Pb system in monazite during metamorphism, deformation, and fluid circulation events.

The purpose of this paper is to describe a revised age-map procedure, updated from that published by Williams et al. (1999), and to illustrate some of the capabilities and limitations of age mapping as currently implemented. We present three monazite age map examples from granulites: one from Canada (Snowbird Tectonic Zone) and two from Madagascar (mafic Andriamena unit) that illustrate the types of geochronologic insights that the maps can provide. A second purpose of the paper is to give access to a new program for making and displaying age maps from compositional images for all researchers interested in monazite

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