Brittle fracturing and fracture healing of zircon: An integrated cathodoluminescence, EBSD, U-Th-Pb, and REE study

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ABSTRACT

The entire population of magmatic oscillatory zoned zircons in a migmatitic granite from the Tjärnesjö intrusion, southwest Sweden, reveal fine-scale brittle fracturing. The oscillatory zoned fragments are rotated but not dispersed. Fractures between individual fragments are sealed by newly formed CL-bright zircon. Hydraulic fracturing is the most probable mechanism. The internal structure of fractured zircons and the LREE-enriched, low Th character of CL-bright zircon both suggest that cracks between oscillatory zoned zircon fragments were rapidly sealed after fracturing by CL-bright zircon, precipitated from hydrothermal fluids. Zircon fracturing and crack-sealing has been dated by SIMS ion-probe and U-Th-Pb isotopes to 920 ± 51 Ma (lower intercept age, 2σ, MSWD = 1.09) with a limit for the youngest possible age of 960 ± 16 Ma (207Pb/206Pb, 2σ, MSWD = 0.23) dated by sector-zoned rims forming overgrowths on the fractured cores.

Keywords: Zircon, hydrothermal, cathodoluminescence, U-Pb, Sveconorwegian, SIMS, EBSD, fracturing, hydraulic

INTRODUCTION

Zircon is the mineral routinely used for geochronology of granitic and high-grade metamorphic rocks. Development of high-spatial-resolution instrumentation used for in situ U-Th-Pb zircon dating, such as secondary ion mass spectrometer (SIMS), has improved the ability to use zircon to date complex igneous and metamorphic events, rationalized with integration of cathodoluminescence (CL) and back-scattered electron (BSE) imaging and mineral-chemistry data to connect petrogenetic information to precise geochronology (e.g., Hanchar and Hoskin 2003). Furthermore, zircon can form in a wide variety of geological environments, from very low-grade metamorphic conditions at 250 °C (Rasmussen 2005) to mantle conditions, such as kimberlitic zircons (Kinny and Dawson 1992). Its exceptional ability to survive high-grade metamorphism and host-rock melting has many applications in studying the evolution of the crust.

Despite the importance of zircon in geochronology and petrogenesis, its response to deformation is relatively unstudied, with only a few studies from mylonite/ultramylonite zones (Boullier 1980). Wayne and Sinha (1988) studied fracturing of zircon and associated Pb loss in an ultramylonite, whereas Steyer and Sturm (2002) used zircon as a passive marker for calculations of mass and volume changes during deformation. Zircon deformation and phase transition during experimental shock experiments (Leroux et al. 1999) and plastic deformation at crustal conditions (Reddy et al. 2006) addresses zircon deformation in great detail. A few images of fractured zircon with healed fractures from lower crustal xenoliths (Schmitz and Bowring 2000) and ophiolites (Rubatto et al. 1998) have been published, but the mechanisms of fracturing and fracture healing were not discussed.

In this paper, we combine geochronological and mineral-chemistry data with detailed CL and backscatter electron imaging and electron backscatter diffraction (EBSD) analysis of fractured and healed zircons from the migmatitic Tjärnesjö granite in SW Sweden. We discuss possible fracturing and fracture-healing mechanisms in zircon in the context of the metamorphic evolution of these migmatitic granites.

REGIONAL GEOLOGIC SETTING

The Sveconorwegian province in southwest Sweden consists of Eastern (ES) and the Western Segments (WS) (Fig. 1). The ES, where the Tjärnesjö intrusion is situated, is dominated by ca. 1.70–1.66 Ga felsic to intermediate orthogneisses (Ahlin et al. 1985; Connelly and Åhäll 1996; Johansson 1998; Söderlund et al. 2002). Regional Sveconorwegian metamorphism in the ES reached upper-amphibolite to high-pressure granulite facies (Johansson et al. 2001). Metamorphic zircon ages from high-pressure granulites, garnet-bearing amphibolites, migmatitic gneisses and pre-tectonic pegmatites are 0.99–0.96 Ga (Andersson et al. 1999; Cornell et al. 1997; Johansson 1998; Söderlund et al. 2002). Regional Sveconorwegian metamorphism in the ES reached upper-amphibolite to high-pressure granulite facies (Johansson et al. 2001). Metamorphic zircon ages from high-pressure granulites, garnet-bearing amphibolites, migmatitic gneisses and pre-tectonic pegmatites are 0.99–0.96 Ga (Andersson et al. 1999; Cornell et al. 1997; Johansson 1998; Söderlund et al. 2002).