Beryl stability in local hydrothermal and chemical environments in a mineralized granite

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ABSTRACT

The temperature and chemistry of hydrothermal fluids control the breakdown and formation of beryl in rocks of appropriate bulk composition. In rocks of the Triberg granitic complex in the Schwarzwald, Germany, late-magmatic to hydrothermal greisen fluids interacted with beryl-bearing pegmatites and the leucogranitic host rocks over a range of temperatures, but the greisen overprint was not pervasive. As a result, it is possible to examine the effects of the greisen fluids on beryl stability and the host granitic rock over a range of temperatures. Replacement of primary (pegmatitic) beryl resulted in the formation of secondary beryllicium minerals. At high temperature (~550 °C), gem-quality aquamarine was precipitated in vugs with alteration halos of albite, muscovite, cassiterite, and fluorite. At lower temperatures (~250 °C), blue anhedral beryl replaced potassium feldspar in granite adjacent to fractures. At slightly lower temperatures (~220–230 °C), pegmatitic beryl was replaced by kaolinite ± bertrandite ± phenakite.

Calculated activity and phase diagrams suggest that precipitation of secondary beryl depends chiefly on variations in the ratio Na/K in the fluid. These same fluids were responsible for the albite and white mica formation in the surrounding granite. Further, the effective fluid-to-rock ratio determines the progress of the alteration reactions, which in turn determines the ability of the fluid to precipitate beryl. On the basis of fluid-inclusion measurements and the activity-diagram calculations, a pH of about 5 (at ~550 °C and 4% NaCl equivalent) was estimated for the fluids that caused the mineralization.

INTRODUCTION AND GEOLOGIC SETTING

The Triberg granite complex (Fig. 1) in the central Schwarzwald, southwestern Germany, is a composite Variscan batholith that is composed of granodiorite, monzogranite, leucogranite, and a transitional leucogranite, which is believed to represent a hybrid of the monzo- and the leucogranitic melts (Schleicher 1978, 1984, 1994; Schleicher and Fritsche 1978). Werchau et al. (1989) determined an intrusion age of 325 ± 5 Ma (U/Pb in monazite).

The leucogranite is the youngest of these granitic bodies and crosscuts the other units. The leucogranitic melt was water undersaturated and interpreted as the product of a low degree of partial melting of metamorphosed sedimentary rocks in the lower crust during the relaxation after the collisional stage of the Variscan orogeny (Schleicher 1994). The leucogranite consists of potassium feldspar, quartz, plagioclase (An$_{12}$–22), muscovite, biotite [Fe/(Fe + Mg) = 0.93–0.95], and pinite pseudomorphs after cordierite (Schleicher 1994). The SiO$_2$ content ranges from 76 to 79%, the Al$_2$O$_3$ content from 12 to 13.7%, and the total volume of mafic minerals is <5%. Contents of REE, Zr, Ba, and Sr are low, and Th, Y, Ga, and Rb/Sr are high (Schleicher 1994), which is typical for leucogranites. Additionally, the leucogranite contains small pegmatitic lenses with tourmaline and, less commonly, beryl as well as cassiterite + fluorite + topaz greisen assemblages (Markl 1994; Markl and Schumacher 1996). However, the beryl and the greisen assemblages are concentrated in a small area of the leucogranite.

The greisen zone was described in more detail by Markl (1994) and Markl and Schumacher (1996), and only the main features are outlined below. The beryl- and cassiterite-bearing areas are nearly identical and restricted to a 4 × 8 km region that is centered around the village of Niederwasser (Fig. 2). In this area Markl and Schumacher (1996) showed that temperature and geochemical gradients in the fluids extended roughly radially outward from a center of greisen activity. Temperatures near the center of greisen activity were estimated to be about 550 °C at 1500 bar; at the margins of the greisen zone, fluid temperatures were about 250 °C at 1500 bar. The temperature decrease correlates with a decrease by a factor between 15 and 40 in $a_{H_2O}$ of the fluids. The simplest model of these features is concentric gradients in temperature and composition of the greisen fluids. Accordingly, distance from the center of mineralization (Fig. 2) should give a rough estimate of the properties of the fluids. The formation of the primary beryl-bearing assemblages (pegmatites) was the earlier event, and the overprinting of it