Metastability of sillimanite relative to corundum and quartz in the kyanite stability field: Competition between stable and metastable reactions

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ABSTRACT

The formation of sillimanite, under metastable conditions, relative to corundum and quartz has been defined experimentally, approximately 700 to 800 MPa inside the kyanite stability field thereby allowing for the approximate location of the metastable Sil = Cnd + Qtz equilibrium to be outlined in P-T space from 600 to 800 °C. Experiments involved using a NaCl assembly with a graphite furnace in a two-piston-cylinder apparatus. The thermocouple tip was in direct contact with the flat-lying, folded Pt capsule thereby minimizing thermal gradients to <5 °C. Charges consisted of equimolar amounts of gem-quality sillimanite, corundum, and quartz, plus H2O as a flux, placed in a 1.3 cm long Pt capsule that was arc-welded shut and folded. During the course of the experiment, the metastability of the assemblage Sil-Cnd-Qtz implies that Sil ↔ Cnd + Qtz is, at some point, in direct competition with Cnd + Qtz → Ky and Sil → Ky. Early during the experiment it may be assumed that a steady state between dissolution and growth rates is established. However, due to the sluggish nucleation of kyanite, there is a P-T dependent induction period during which Cnd + Qtz → Sil is the controlling reaction. Once kyanite does appear, the reaction proceeds very fast to kyanite via reactions Cnd + Qtz → Ky and Sil → Ky. The kyanite surface area is probably a major factor in controlling the overall reaction rates. Under constant P and T, the system evolves from metastable sillimanite formation to sillimanite consumption, which is only dependent on the kyanite surface area. Similar competition between stable and metastable reactions could occur during contact metamorphism where metastable mineral growth is observed. The relative sluggishness of all three reactions under relatively dry conditions could help to explain the persistence of metastable corundum + quartz ± Al2SiO5 assemblages in nature.

Keywords: Sillimanite, kyanite, corundum, quartz, rate of reaction, experimental petrology, Rietveld refinement, aluminosilicates

INTRODUCTION

In nature, corundum in direct contact with quartz, ± a sillimanite rim along the corundum-quartz boundary, is known to occur in high-grade to ultrahigh-grade, aluminous, metamorphic rocks in a wide variety of locations including Antarctica, South Africa, India, Europe, and North America (e.g., Harris 1981; Powers and Bohlen 1985; Tracy and McLellan 1985; Santosh 1987; Lal et al. 1987; Perchuk et al. 1989; Motoyoshi et al. 1990; Waters 1991; Dasgupta and Ehl 1993; Hiroi et al. 1994; Guiraud et al. 1996; Shaw and Arima 1998; Mouri et al. 2003, 2004). In a series of recent studies documenting natural observations of apparently stable corundum + quartz ± sillimanite assemblages by Guiraud et al. (1996), Shaw and Arima (1998), and Mouri et al. (2003, 2004), there has been an ongoing discussion, based in part on the experimental work of Anovitz et al. (1993), concerning whether or not corundum and quartz could represent a stable assemblage under certain ultrahigh-grade metamorphic P-T conditions, i.e., >1000 °C and 1200 MPa, as well as what role substitution of a minor Fe component into sillimanite might play with regard to increasing the stability field of corundum + quartz relative to sillimanite (e.g., Guiraud et al. 1996). Other workers have suggested that the existence of corundum in direct contact with quartz under dry granulite-facies conditions, without any sillimanite having formed, more likely indicates that the reaction between corundum and quartz is quite sluggish under such conditions (e.g., Motoyoshi et al. 1990).

From a purely experimental standpoint, the location of the metastable Sil-Cnd-Qtz equilibrium within the kyanite stability field has never been located in P-T space. This fact, as well as the occurrence and possible stability of the assemblage corundum + quartz ± sillimanite in nature, has motivated a new series of experiments involving sillimanite in the Al2O3-SiO2 system with two specific goals. The first of these was to experimentally define the approximate location in P-T space of the metastable equilibrium of sillimanite relative to corundum and quartz in the kyanite stability field, over a series of temperatures within the time period of a few hours to a few weeks. The second goal was to relate the various reaction rates between kyanite, sillimanite, corundum, and quartz, within the kyanite stability field, for a