Transformation of igneous quartz to high-purity quartz in granitic pegmatites of South Norway

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ABSTRACT

Quartz in syntectonic abyssal pegmatites has been studied by LA-ICP-MS, SEM-CL and optical petrography in order to constrain processes generating high-purity quartz (HPQ), i.e. quartz with very low trace element contents. The presence of HPQ in pegmatites that normally contain igneous quartz with high trace element contents is poorly understood. This paper shows that the formation of HPQ is governed by recrystallisation of magmatic quartz which prepares ground for subsequent episodes of replacement by hydrothermal HPQ.

Keywords: *Quartz, pegmatite, syntectonic, hydrothermal, LA-ICP-MS, SEM-Cl.*

INTRODUCTION

The increasing demand for high-purity quartz (HPQ) in the production of solar-grade silicon and other high-tech products has encourage research on geological processes generating HPQ. Processed concentrates of HPQ contain <50 μgg^{-1} of trace elements (Harben, 2002) confined to mineral impurities, fluid inclusions and to simple and coupled substitutions of Si^{4+} in the crystal lattice. The two former types of impurities can largely be removed by different mineral processing techniques. The lattice-bound trace elements, however, are not easily removed and therefore the quartz quality is largely dependent on the amount of these elements. Primary magmatic quartz of pegmatites is known to contain high concentrations of lattice-bound trace elements (Larsen et al. 2004, Götze et al. 2005) that generally exceed the trace element contents of HPQ with several orders of magnitude. Still, HPQ concentrates are being produced from pegmatites and the present paper addresses the processes that transform igneous pegmatite quartz into HPQ.

SETTING

The pegmatite fields in South Norway developed during two stages of the Sveconorwegian orogeny (1.13-0.9 Ga). The first generation of pegmatites dealt with in this contribution comprises syntectonic and anatectic pegmatites formed at peak-metamorphism (~1.1 Ga). They show no clear spatial relationships with coeval granite plutons in contrast to a second generation that are largely undeformed and situated in the endo- and exocontact of coeval late-tectonic granites (~0.9 Ga). The first generation of pegmatites can be classified as synkinematic abyssal (AB) biotite pegmatites and muscovite pegmatites, in some areas developed as AB-HREE and AB-LREE pegmatites of Černý and Ercit (2005). They mostly represent simple pegmatites which in some areas grade into pegmatitic granites. Zoned pegmatites with cores of massive quartz surrounded by blocky feldspar are common whereas more fractionated types with cleavelandite and sodic aplites are relatively rare. The pegmatites intruded during amphibolite (sillimanite grade) to granulite facies metamorphism (1.08-1.13 Ga) and are often affected by folding and ductile shearing, attesting to their syntectonic development (Henderson and Ihlen, 2004).

TRACE ELEMENTS IN QUARTZ

LA-ICP-MS analyses of lattice-bound trace elements reveal that most of the pegmatitic quartz exceeds a total impurity content of 50 μgg^{-1}, thus falling outside the range of HPQ. However, quartz intergrown with late cleavelandite and albite is generally low in Ti (<10 μgg^{-1}). The contents of Al and Ti are highly variable, but rarely fall within the HPQ field in Al-Ti diagrams with upper limits defined as Al = 25 μgg^{-1} and Ti = 10 μgg^{-1} (Müller et al., 2005). Quartz in peraluminous muscovite pegmatites contains high concentrations of both Al (25-300 μgg^{-1}) and Ti (<60 μgg^{-1}), whereas quartz in metaluminous biotite pegmatites shows lower levels of Al (25-100 μgg^{-1}) and Ti (<20 μgg^{-1}). Quartz in pegmatites formed under high-grade metamorphic conditions contains 300 μgg^{-1} Al and 100-350 μgg^{-1} Ti. These trace element characteristics emphasize the importance of both temperature (Ti substitution; Wark and Watson, 2006) and magma composition (Müller et al., 2002) on the quartz chemistry.

FORMATION OF HPQ

SEM-CL and optical petrography reveal that the pegmatitic quartz comprises a mixture of multiple quartz generations (Larsen et al. 2004). The primary igneous quartz occurs as coarse clear-to-smoky grains, which are partially or fully recrystallised into fine-grained granular aggregates with a greatly increased surface area. This enhances fluid access during subsequent episodes of fracturing and fluid infiltration when multiple generations of hydrothermal quartz are formed by replacement along grain boundaries, as well as along microfractures (Fig. 1, next page).

The recrystallisation is apparently related to sub-solidus reactions, amphibolite facies deformation and/or initial high-T retrogression under relatively anhydrous conditions. Therefore the recrystallised quartz largely preserves the trace element composition of the primary magmatic quartz. During subsequent episodes of fracturing and fluid influx hydrothermal quartz precipitates, replacing the already recrystallised quartz.

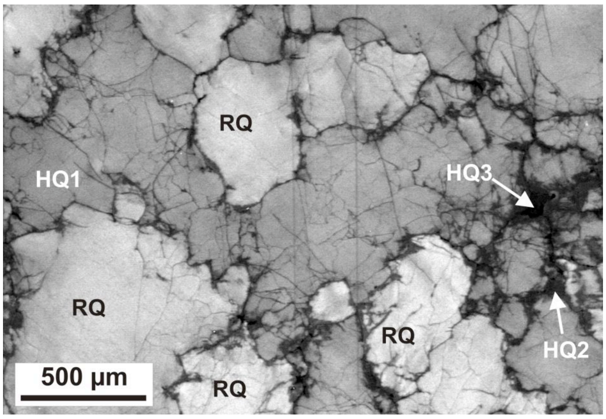

FIGURE 1. SEM-CL image of fine-grained aggregates of recrystallised quartz (RQ) being replaced by hydrothermal quartz (HQ1). Both are in turn replaced by low luminescent HQ2 enveloping micro-fractures and grain boundaries filled with HQ3.

The amount and composition of hydrothermal quartz are cont-rolled by a number of variables including PT-path of the tectonic uplift, fluid composition, structural permeability, water/rock ratio and duration of the water-rock interaction. Prolonged exposure at high W/R ratios and at relatively low T promotes the complete transformation to hydrothermal HPQ. This is demonstrated by Mesoproterozoic pegmatites in SW Norway being overprinted by green-schist facies and associated incursion of metamorphic fluids during the Scandian phase (0.43-0.40 Ga) of the Caledonian orogeny. In these pegmatites, only few relics are left of Mesoproterozoic recrystallised quartz within grains of hydrothermal quartz, yielding HPQ compositions (Fig. 2).

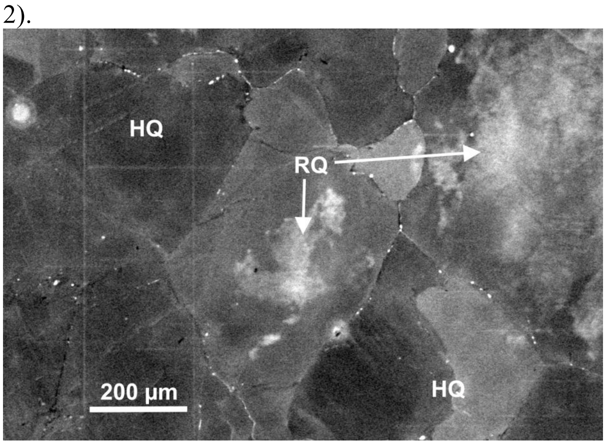

FIGURE 2. SEM-CL image of fine-grained aggregates of high-purity hydrothermal quartz (HQ) containing relics of bright luminescent recrystallised quartz (RQ).

CONCLUSIONS

The transformation of igneous quartz to HPQ in pegmatites is a fluid-induced process mainly occurring in syntectonic pegmatites. The magmatic quartz recrystallised in conjunction with sub-solidus reactions and episodes of tectonic uplift into finer-grained quartz preserving the magmatic element signature. Extensive fluid influx and hydrothermal re-placement of the recrystallised igneous quartz during subsequent uplift, deformation and/or retrogradation are the main processes in the formation of HPQ. High water/rock ratios and the infiltration of relatively low-T fluids are the most important parameters controlling its development in synkinematic pegmatites.

REFERENCES CITED

Černý, P. & Ercit, T.S. (2005) The classification of granitic pegmatites. The Canadian Mineralogist, 43, 2005-2026.

Götze, J., Plötze, M. & Trautmann, T. (2005) Structure and luminescence of quartz from pegmatites. American Mineralogist, 90, 13-21.

Harben, P.W. (2002) The industrial mineral handybook. Industrial Mineral Information, Worcester Park, United Kingdom, 4th edition, pp. 412

Henderson, I. & Ihlen, P.M. (2004) Emplacement of poly-generation pegmatites in relation to Sveconorwegian contractional tectonics: examples from southern Norway. Precambrian Research, 133, 207-222.

Larsen, R.B., Hendersen, I., Ihlen, P.M. & Jacamon, F. (2004) Distribution and petrogenic behaviour of trace elements in granitic pegmatite quartz from South Norway. Contributions to Mineralogy and Petrology, 147, 615-628.

Müller A., Kronz A., & Breiter K. (2002) Trace elements and growth patterns in quartz: a fingerprint of the evolution of the Podlesí Granite System (Krušné Hory, Czech Republic). Bulletin of the Czech Geological Survey, 77, 135-145.

Müller A., Ihlen P.M. & Kronz A. (2005) Potential resources of quartz and feldspar raw material in Sørland IV: Relationships between quartz, feldspar and mica chemistry and pegmatite type. Geological survey of Norway report, 2005.075, pp. 104.

Wark, D.A. & Watson, E.B. (2006) TitaniQ: a titanium-in-quartz geothermometer. Contributions to Mineralogy and Petrology, 152, 743-754.