QUARTZ AND GARNET CHEMISTRY OF SOUTH NORWEGIAN PEGMATITES AND ITS IMPLICATIONS FOR PEGMATITE GENESIS

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INTRODUCTION

The granitic pegmatites of southern Norway formed during the Sveconorwegian (Grenvillian) orogen at about 1 billion years ago at the western margin of the Fennoscandian shield. This part of the Sveconorwegian orogen comprises exhumed Mesoproterozoic volcanic arcs of the Bamble Complex, thrust over the Telemark Block along the Porsgrunn-Kristiansand Fault Zone (PKFZ; Fig. 1). The thrusting was associated with the injection of an enormous number of granitic pegmatites forming the Bamble-Evje Pegmatite Cluster (BEPC). The BEPC covers an area of more than 10,000 km^2 and comprises - from W to E - the pegmatite fields of Evje-Iveland, Glamsland-Lillesand, Froland, Arendal, Søndeled, and Kragerø. The BEPC pegmatites are relatively homogenous in composition and primitive in respect to the granite differentiation (e.g., Larsen 2002, Müller et al. 2008). Two groups of pegmatites can be distinguished applying the classification of Černý and Ercit (2005): (1) simple abyssal pegmatites (AB-HREE) and (2) rare-element (REL-REE) pegmatites. The first group is predominantly represented by the pegmatite fields of Glamsland-Lillesand, Froland, Arendal, and Søndeled, and the second group by the Evje-Iveland and Kragerø fields.

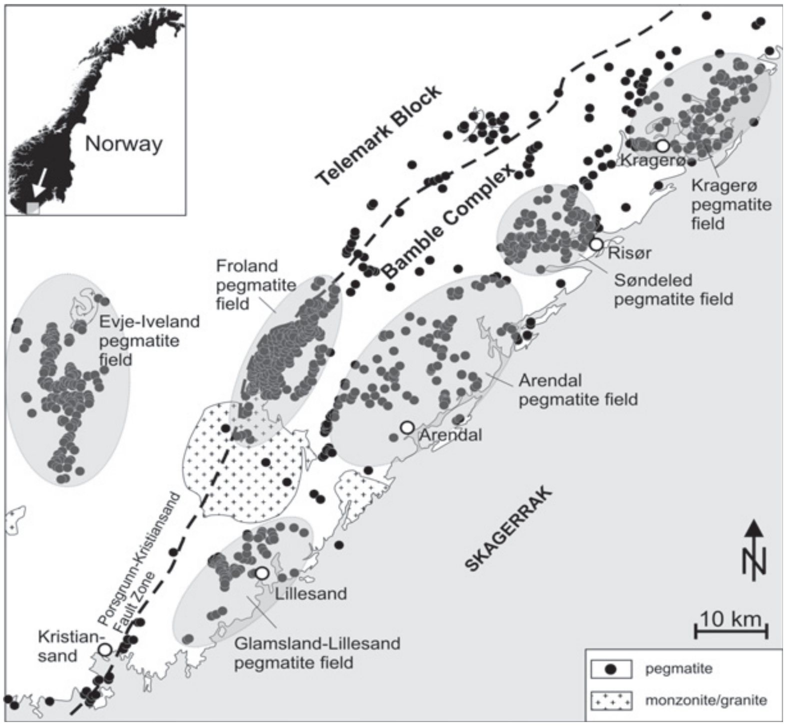

Figure 1- Distribution of major pegmatites in the BEPC comprising the pegmatite fields of Evje-Iveland, Glamsland-Lillesand, Froland, Arendal, and Kragerø.

In this study we compare the chemistry of quartz and garnet of syn-orogenic pegmatites of Evje-Iveland and Froland. Each of the two pegmatite fields is representative for one of the two pegmatite groups occurring in the BEPC. Both fields contain late-orogenic granite intrusions at their periphery. The Froland pegmatite field is situated immediately above the thrust zone along the PKFZ, whereas the Evje-Iveland field to the west developed in the interior of the Telemark Block in the foot wall of the thrust zone (Fig. 1). The pegmatites of both fields consist of quartz, alkali feldspar, plagioclase, biotite, and minor white mica. REE minerals and other striking accessories are rare in Froland. In contrast, the pegmatites of Evje-Iveland become famous for their contents of rare-element minerals (e.g., Brøgger 1906) in particular Sc-bearing minerals, many of them being discovered and described for the first time in the world (e.g., Schetelig 1922).

The aim of the study is to utilise the chemistry of pegmatitic quartz and garnet in order to better understand the contrast between the relative homogeneous and primitive bulk chemistry and the high variability in accessory chemistry of the two pegmatite fields. We applied this type of approach because (1) minor variations of the bulk chemistry of the pegmatites are hard to determine due to the internal zoning of the pegmatite bodies and the large crystal size of up to several meters, and (2) the understanding of the processes controlling trace-element uptake into the lattice of igneous quartz is advancing (e.g., Wark & Watson 2006, Breiter & Müller 2009, Jacamon & Larsen 2009).

QUARTZ CHEMISTRY

The concentrations of Li, Be, B, Al, Ge, P, K, Ti, and Fe in pegmatite quartz were determined by laser ablation inductively-coupled mass spectrometry (LA-ICP-MS). Variations of the most significant trace elements are plotted in the concentration diagrams of Figure 2. For comparison the trace element concentrations of pegmatitic quartz (latest quartz generation) of the highly peraluminous (S-type) Podlesí granite system and slightly peraluminous (A-type) Hora svaté Kateřiny (Katerina) granite system of the Krušne Hory, Czech Republic, are plotted (Breiter & Müller 2009).

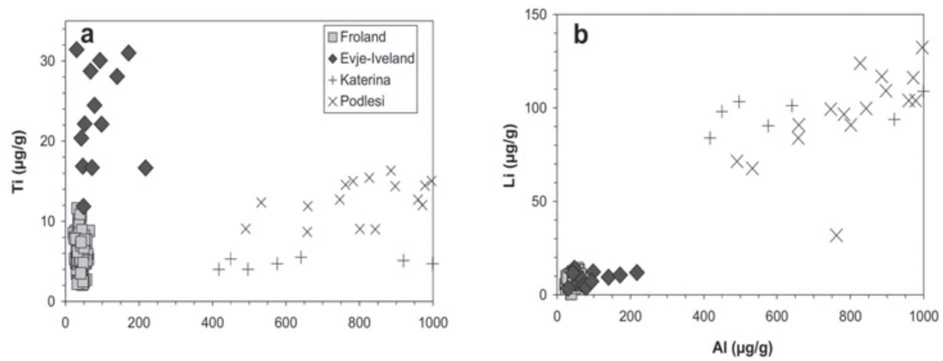

Figure 2 - Contents of trace elements in quartz (µgg^{-1}) determined by LA-ICP-MS: a - Al versus Ti; b - Al versus Li. The concentrations of the Evje-Iveland quartz represent average concentrations (3 to 6 analyses) of individual pegmatite localities (see Larsen et al. 2004).

Al concentrations of both the Froland and Evje-Iveland quartz are low and relatively consistent compared to the high evolved pegmatitic quartz from Krušne Hory. However, the Al concentrations of the Evje-Iveland quartz are slightly higher and have higher variability than that of the Froland quartz (Fig. 2a). The major difference between quartz of both pegmatite fields is the Ti content. The average Ti content of the Evje-Iveland quartz is 23 µgg^{-1} (n=69) and of the Froland quartz 6 µgg^{-1} (n=137). The corresponding quartz crystallisation temperatures are 597°C (range: 534-633°C) and 494°C (range: 421-550°C), respectively, applying the Ti-in-quartz geothermometer of Wark & Watson (2006). Thus, the Evje-Iveland pegmatites crystallised at significant higher temperatures than the syn-orogenic Froland pegmatites. Concentrations of Li, Be, B, Ge, P, K, and Fe are in the same range for both pegmatite fields.

The Al and Li content of igneous quartz is a sensitive indicator of the differentiation degree of the quartz-forming silicate melt (e.g., Breiter & Müller 2009). Thus, the low Al and Li concentrations in quartz of the south Norwegian pegmatites compared to the quartz from the Krušne Hory reflect clearly their homogeneous and primitive bulk chemistry (Fig. 2b).

GARNET CHEMISTRY

The chemistry of garnets from the Froland and Evje-Iveland pegmatite field was determined by electron microprobe. The spessartine-rich garnets (28 to 64 mol% spessartine) of both pegmatite fields are characterised by high and variable Y_2O_3 (0.05-2.31 wt.%), the strong enrichment of HREE, and traceable Sc in the range of 0-310 $\mu g g^{-1}$. The major difference is the significant higher CaO content of the Froland garnets compared to the Evje-Iveland garnets (Fig. 3). Thus, the garnet-forming silicate melts of Froland were more enriched in Ca than the Evje-Iveland melts.

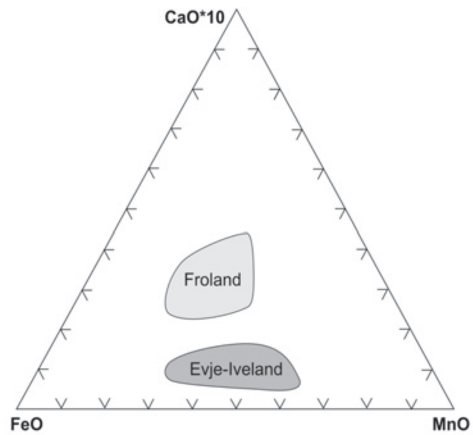

Figure 3 - Ternary diagram of FeO, MnO and CaO concentrations in garnets from Evje-Iveland and Froland pegmatites. The data fields are based on 188 electron microprobe measurements.

DISCUSSION

The analyses of quartz and garnet of the REL-REE pegmatites of Evje-Iveland and AB-HREE pegmatites of Froland revealed two minor chemical differences which are probably very significant for the understanding of the variation of their rare-element content:

The relative high Ti content of the pegmatite quartz of Evje-Iveland indicates crystallisation temperatures of about 600°C, whereas the Froland pegmatites crystallised at about 500°C. The higher crystallisation temperature and the extraordinary position of the Evje-Iveland pegmatites in respect to the BEPC (Fig. 1) imply that an additional heat source triggered the ascent of the Evje-Iveland melts, which were generated during the Sveconorwegian thrusting (Henderson & Ihlen 2004). It is suggested that the heat was provided by a subsurface intrusion probably of syenitic to granitic composition, which is typical for the late-Sveconorwegian (Grenvillian) stage (e.g., Andersen 1997).

The higher Ca content of the garnets from Froland compared to the Evje-Iveland garnets implies higher Ca concentrations in the silicate melts forming the Froland pegmatites. This in turn indicates that the degree of partial melting was higher for the Froland melts, which seems to be in contrast to the relative low crystallisation temperature. Thus, the Evje-Iveland pegmatite melts were probably more peralkaline compared to the Froland melts.

The assumption is supported by common occurrence of "cleavelandite" (albite variety) in the Evje-Iveland pegmatites. Increasing peralkalinity of the pegmatite-forming melts result in increasing water solubility and mobility of Y, REE, and other rare-elements (e.g., Petersson & Eliasson 1997). The solubility of these elements is further enhanced by increasing temperature and water activity, which would explain the enrichment of Y, HREE and other rare elements in the Evje-Iveland pegmatites.

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