Quartz chemistry of the Julianna pegmatites and their wall rocks, Piława Górna, Poland: implications for the origin of pegmatite melts

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Introduction

The traditional model for rare element pegmatite genesis involving a cogenetic granite with a zoned pegmatite field with increasingly more evolved pegmatites at larger distance from the parental granite (e.g., Černý, 1991a, 1991b; London, 2008; Černý et al., 2012) implies that (1) a granite intrusion is present in the vicinity of the pegmatite field and (2) the granite and pegmatites should be of essentially the same age. Many examples for such pegmatite fields are found worldwide. However, recent advances in age determination of pegmatites reveal that there are a number of rare element pegmatite fields that do not show a temporal relation to a parental granite, most likely did not form from evolved late-stage melts, but may represent highly enriched partial melts in migmatite belts (Beurlen et al., 2014; Simmons et al., 1996, 2013; Cronwright, 2014).

The Julianna pegmatite suite, exposed since 2009 in the Piława Górna quarry, 1.5 km N of the Piława Górna town in the Góry Sowie Block (GSB), SW Poland, may represent another example of rare element pegmatites formed by partial melting of host rocks that consists of geochemically contrasting amphibolites and paragneisses (Pieczka et al., 2015). Dating of the Julianna pegmatites yielded the emplacement ages of 380.7±2.4 Ma (U–Pb–Th uraninite) and 377.6±1.3 Ma (U–Th–Pb monazite) (Pieczka et al., 2015; Turniak et al., 2015). The ages of the nearby Variscan granitoids of the Strzegom–Sobótka massif and the Niemcza Zone are 308-294 Ma (Turniak et al., 2014) and 335-340 Ma (Oliver, 1993; Pietranik et al., 2013), respectively, excluding these granites as a possible source of the pegmatite melts. However, the ages of the Julianna pegmatites and other GSB pegmatites (c. 370 Ma; Van Breemen et al., 1988; Timmermann et al., 2000) are coeval with the anatectic melting of metasediments and metavolcanites of GSB at 385–370 Ma (Kryza & Fanning 2007 and references therein).

Julianna pegmatites comprise a broad range of pegmatitic bodies with various degrees of textural differentiation and geochemical fractionation ranging from primitive homogeneous to weakly zoned dikes with NYF affinity to highly fractionated, zoned pegmatites with hybrid NYF-LCT characteristics (e.g. Pieczka et al., 2015). The pegmatites intruded along a NNE–SSW running zone of strongly tectonized amphibolite. Dikes, apophyses and lenticular bodies, up to 6 m thick, form a complex network extending along 30–40 m in vertical section and 80–100 m in planar view. The host rocks exposed in the quarry comprise gneisses and amphibolites, both partly migmatized. The amphibolites contain bodies of retrograde eclogite that bear record of the eclogite stage metamorphic event that took place c. 390 Ma at 730–840°C and at 2.0–2.5 GPa and was followed by rapid, nearly isothermal decompression (Ilnicki et al., 2011, 2012; Nejbert et al., 2013).

The evolved pegmatites exhibit a simple zoning pattern. One pegmatite dyke contained instead of a centrally located quartz core a lithium mica–‘cleavelandite’–quartz zone and a spodumene–‘lepidolite’ core. Nodular pockets, up to 30 cm large, composed of pollucite, Li–Rb–Cs micas, unidentified zeolites and smectites were found within or adjacent to the replacement zones of saccharoidal albite. These Li-Cs-enriched zones have typical LCT characteristics and, thus, this pegmatite is considered as mixed NYF-LCT pegmatites. Petrography and mineralogy of the Julianna pegmatites have been systematically studied (e.g. Pieczka et al., 2012, 2013, 2014, 2015, 2016; Szuszkiewicz et al., 2013).

The aim of this study is to utilize the trace element signature of quartz from the migmatitic paragneiss and amphibolitic host rocks and from different pegmatite types to better understand the origin of the pegmatite melts.

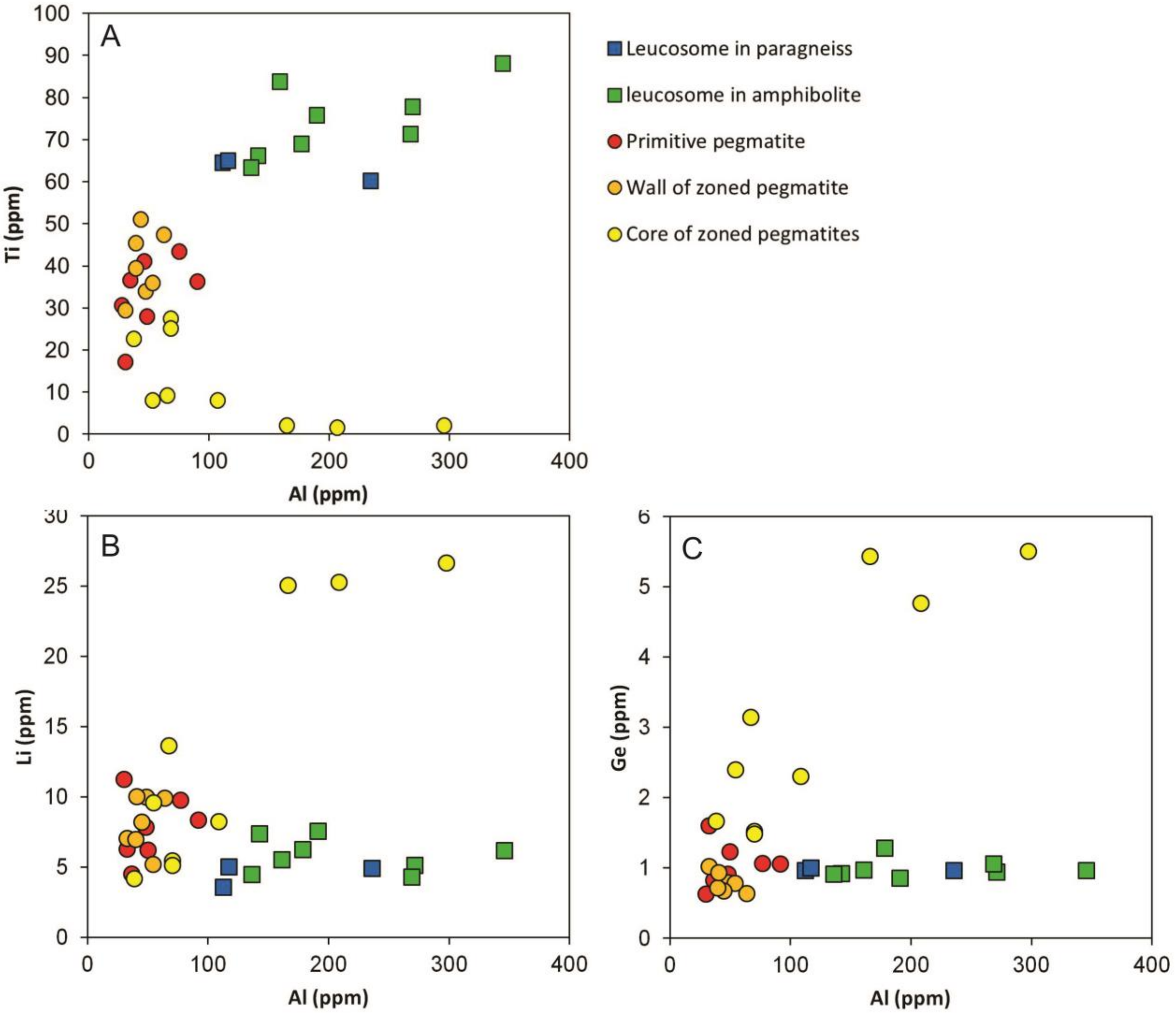

Figure 1. *Trace element concentrations in quartz from leucosomes in migmatitic paragneiss and amphibolite (pegmatite host rocks), primitive pegmatites and evolved zoned pegmatites from the Piława Górna quarry, determined with LA-ICP-MS.*

Table 1. *Quartz crystallization temperatures (in Celsius degrees) calculated using the Ti-in-quartz geothermobarometer by Huang & Audétat (2012) assuming a Ti activity of* a_{Ti}*=1; n –number of analyses.*

Rock type	**n**	**3kbar**	**5kbar**	**10kbar**	**15 kbar**	**20kbar**	**25kbar**
Migmatites	3	705±4	755±5	837±5	896±5	943±5	983±6
Amphibolites	8	723±13	774±14	858±15	918±16	965±16	1006±17
Primitive pegmatites	7	636±30	682±31	759±34	813±35	857±37	894±38
Wall of zoned pegmatites	7	657±20	704±21	782±23	838±24	883±25	920±25
Core of zoned pegmatites	9	516±85	556±90	623±97	670±102	708±106	740±109

Results

Trace element analyses of quartz from pegmatites and their host rocks (migmatized amphibolites and paragneisses) were performed with LA-ICP-MS at the Geological Survey of Norway in Trondheim. Concentrations of Al, Ti, Li and Ge, which are, generally, the most common trace elements in quartz, are plotted in Fig. 1. Average concentrations of Al in quartz from migmatites and mm-sized leucosomes in amphibolite are in the range of 155±70 ppm and 212±75 ppm, respectively. Quartz of primitive pegmatites and from wall zones of evolved zoned pegmatites has much less Al of 52±24

ppm and 46±10 ppm, respectively. The Al content increases again to 120±87 ppm in quartz from the core of zoned pegmatites. Both trends show a systematic, continuous decrease of Al from host rock to primitive pegmatite and an increase of the element concentration from wall to core of zoned pegmatites. In contrast, the general decrease of the Ti content quartz from leucosomes in paragneisses and amphibolites, primitive pegmatites to evolved pegmatites is discontinuous (Fig. 1A). There is a concentration gap of about 10 ppm Ti between quartz in host rocks and quartz in pegmatites. This gap corresponds to a difference of 50 to 100ºC between the crystallization temperature of quartz in the host rocks and in the pegmatites (Table 1).
Lithium and Ge concentrations in quartz of the host rocks are low compared to pegmatitic quartz (Figs. 1B,C). Lithium increases from leucosomes in paragneisses (4.5±0.8 ppm) and amphibolites (5.9±1.2 ppm) to primitive pegmatites (7.8±2.3 ppm), the wall of zoned pegmatites (8.2±1.9 ppm) and the core of zoned pegmatites (13.7±9.4 ppm). Germanium shows a similar trend (Fig. 1C). Exceptionally high contents of Li and Ge (25.7±0.9 ppm and 5.2±0.4 ppm, respectively) were found in sample P-18 from the core of the most evolved, mixed NYF-LCT pegmatite. This sample has also the lowest Ti (1.5±0.3 ppm) and high Al (224±67 ppm).

Discussion

In Table 1 minimum quartz crystallization temperatures at different pressures are calculated by applying the Ti-in-quartz geothermobarometer by Huang & Audétat (2012). For this calculation a Ti activity of $a_{Ti} = 1$ is assumed. In the case of the quartz core of evolved pegmatites, it is very likely that a_{Ti} was <1 and, thus, these temperatures are not considered here. The temperatures in Table 1 are given for different pressures because the pressure at the time of Julianna pegmatites emplacement has not been investigated so far. According to Ilnicki et al. (2011, 2012) and Nejbert et al. (2013) the peak metamorphic conditions at 730–840°C and at 20-25 kbar at c. 390 Ma recorded by eclogitic relics in the host amphibolites were followed by rapid, nearly isothermal decompression marked by retrograde stages of 680-770°C at 14-17 kbar and 600-700°C at 7-12 kbar or even below 5-7 kbar. These results are in line with the suggested late metamorphic conditions for the GSB of ca. 600-750°C at 4-7 kbar postulated by Kryza & Fanning (2007) and Budzyń et al. (2004) of 600-660°C at 5.2-6.4 kbar. Considering our calculation, the quartz crystallization of 760-860°C in leucosomes of paragneisses and amphibolites happened at 5 to 10 kbar, which might reflect the initial partial melting during the tectonic exhumation in the Variscan orogeny recorded in the GSB. The most realistic crystallization temperatures of pegmatites (c. 700 °C) correspond to pressures of about 5 kbar (primitive pegmatites and wall of zoned pegmatites). Considering the age of pegmatite formation (383 to 376 Ma; Pieczka et al., 2015; Turniak et al., 2015) the assumed pressures representing a stage of the isothermal uplift are plausible.

The temperature gap of 50 to 100ºC between the crystallization temperature of the quartz in the host rocks and quartz in the pegmatites may have two reasons. Firstly, the Ti activity of the initial pegmatite melts (represented by primitive pegmatites and the wall of zoned pegmatites) were <1 or, secondly, the pegmatites were formed subsequently to the formation of small-scale leucosomes in the host rocks implying that the pegmatite melts originated from greater depth than the today's exposure level. As evidenced by the occurrence of biotite-rich envelopes around larger pegmatite bodies and widespread textural features characteristic of undercooling of the solidifying pegmatite-forming melt, the pegmatitic melts intruded into cooled GSB amphibolites and migmatites. Thus, the second scenario is more likely.

Concluding, results of quartz trace element studies of the Julianna pegmatites and their host rocks support the model that the Julianna pegmatites are genetically related to the migmatization of the GSB rocks during their tectonic exhumation. Paragneisses and amphibolites constitute the most probable source lithologies for the pegmatite-forming melt. The protoliths of the host rocks were greywacke–pelitic–psammitic sequences intercalated with volcanic-arc I-type granitoids (Gunia, 1985; Kröner & Hegner, 1998; Kryza & Fanning, 2007) and mafic rocks of basaltic composition akin to N-MORBs with geochemical signatures suggesting supra-subduction (back-arc basin or volcanic arc) affinities (Ilnicki et al., 2012). Thus, the highly diverse GSB lithology has geochemical potential to generate anatectic melts of a hybrid NYF + LCT signature. However, further studies have to be done to confirm the anatectic model of the genesis of the Julianna pegmatites.

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