Lithos 175–176 (2013) 54–67

Contents lists available at SciVerse ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

# Behavior of trace elements in quartz from plutons of different geochemical signature: A case study from the Bohemian Massif, Czech Republic

Karel Breiter [a,*], Lukáš Ackerman [a], Martin Svojtka [a], Axel Müller [b,c]

[a] Institute of Geology of the Academy of Sciences of the Czech Republic, v.v.i., Rozvojová 269, CZ-16500 Praha 6, Czech Republic
[b] Geological Survey of Norway, NO-7491 Trondheim, Norway
[c] Natural History Museum, Cromwell Road, London SW7 5BD, England, United Kingdom

ARTICLE INFO

*Article history:*
Received 4 October 2012
Accepted 21 April 2013
Available online 6 May 2013

*Keywords:*
Quartz
Trace elements
Granites
Fractionation
Bohemian Massif

ABSTRACT

In this study, the trace-element content in igneous quartz from granitoids of different geochemical types was investigated using the laser ablation ICP-MS technique. The Variscan granitoids in the Bohemian Massif provide an excellent opportunity to study the chemical composition of magmatic quartz from the following granite types: (1) geochemically primitive I-type tonalites and granodiorites, (2) peraluminous S-type two-mica granites, (3) moderately fractionated A-type volcano–plutonic complexes of the Teplice caldera, and (4) highly fractionated S- and A-type rare-metal granites. This diversity of granitoids permitted the study of the chemical composition of magmatic quartz as the result of (i) different magma protoliths and (ii) variable degrees of differentiation. There were only small differences in the quartz trace-element contents, ranging from weakly to moderately differentiated plutons of all geochemical types: Al (mostly in the range between 20 and 250 ppm), Ti (mostly 20–110 ppm), B (<13 ppm), Be (<0.7 ppm), Ge (<1 ppm), Li (<30 ppm), and Rb (<2 ppm). Only the S-type granites from western Erzgebirge contain Al-enriched quartz (mostly 200–400 ppm Al) since the beginning of its evolution. However, quartz from the highly fractionated granites (group 4) differs significantly: this quartz is generally poor in Ti (<20 ppm Ti) and enriched in Al (up to 600 ppm in A-type, and up to 1000 ppm in S-type granites), Be (up to 3.2 ppm), Ge (up to 5.7 ppm), Li (up to 132 ppm, particularly in the S-type granites), and Rb (up to 15 ppm). The contents of the analyzed lithophile elements in the quartz from the highly fractionated granites are similar to the contents reported to be present in evolved complex pegmatites. Although the input of Ti into quartz is controlled mainly by the temperature and pressure of quartz crystallization, the entry of Al into quartz increases as a function of the water and fluorine content of the residual melt. The contents of Ge and Li increase significantly with the fractionation of parental melt. The concentrations of these elements in quartz from highly fractionated granites are controlled by the order of crystallization of the major minerals: comb quartz crystallizing before Li-mica is strongly Li-enriched, whereas groundmass and snowball quartz crystallizing after mica is relatively enriched in Ge.



## 1. Introduction

A number of studies addressing the chemistry of igneous quartz have been published during the last decade as a result of the improvement of micro-analytical methods, such as laser ablation inductively plasma mass spectrometry (LA-ICP-MS), which allow precise determination of very low element concentrations. Although the chemistry of quartz from pegmatites has been reported by several authors (Beurlen et al., 2009, 2011; Götze et al., 2005; Larsen et al., 2000, 2004; Müller et al., 2008a), analyses of quartz from granites are less frequent (Breiter and Müller, 2009; Breiter et al., 2012; Deans, 2010; Jacamon and Larsen, 2009; Müller and Koch-Müller, 2009), as are those from volcanic rocks (Breiter et al., 2012; Müller et al., 2003b, 2005; Watt et al., 1997). Most studies investigating the contents of trace elements in magmatic quartz have described quartz from individual plutons or groups of co-magmatic rocks and have discussed the differences between facies or changes during fractionation (e.g., Jacamon and Larsen, 2009; Müller et al., 2000, 2002, 2003a). In contrast, studies comparing two or more different types of granites are less common (cf. Breiter and Müller, 2009; Müller et al., 2010).

The Bohemian Massif contains granitoids formed during various stages of the Variscan orogeny and covers all the principal geochemical or geotectonic types of granites (I-, S-, and A-types, after the classification of Chappell and White, 1974 and Loiselle and Wones, 1979, or volcanic arc, collisional, and within-plate types, after the classification of Pearce et al., 1984). Although each classification oversimplifies the natural diversity of granitoids, we decided to use the I–S–A-classification in this paper to characterize the major geochemical

* Corresponding author.
*E-mail address:* breiter@gli.cas.cz (K. Breiter).

0024-4937/$ – see front matter 
http://dx.doi.org/10.1016/j.lithos.2013.04.023

and genetic differences among the studied granitoid plutons. The Variscan magmatic activity essentially started with geochemically primitive I-type tonalites and granodiorites (e.g., Sázava-suite in the Central Bohemian Pluton, Fig. 1). This was followed by the common peraluminous S-type two-mica granites (e.g., Eisgarn suite in the Central Moldanubian Pluton) and with the highly fractionated S-type rare-metal granites in the western Krušné hory/Erzgebirge area and terminated with the younger generation of I-type plutons in the southern Moldanubian Unit (Mauthausen and Freistadt intrusions) and A-type volcano–plutonic complexes in the central and eastern Krušné hory/Erzgebirge area (Hora svaté Kateřiny, Teplice caldera) (Cháb et al., 2010; Finger et al., 1997). This diversity of granitoids, therefore, provides an excellent opportunity to study the trace-element signature of magmatic quartz as result of (i) different magma protoliths and (ii) different degrees of fractionation.

The previous studies of the trace elements in magmatic quartz from the Bohemian Massif were focused only on the highly fractionated S- and A-type granites and the rhyolites from the Erzgebirge, Saxothuringian Unit (Breiter and Müller, 2009; Breiter et al., 2012; Müller et al., 2003a, 2005). In this paper, we present an extensive dataset of new laser ablation ICP-MS analyses of quartz from both I- and S-type granitoid plutons from the Moldanubian and Teplá-Barrandian Units of the Bohemian Massif. In combination with the previously published data from Erzgebirge (Breiter and Müller, 2009; Breiter et al., 2012), these new data allow us to discuss the diversity of the chemical composition present in igneous quartz throughout the Bohemian Massif, comprising granitoid plutons of different nature, age, and geotectonic positions (Fig. 2a). The quartz trace-element geochemistry is further compared with the whole-rock chemistry to provide a complex insight into the behavior of trace elements in granitic systems with respect to different types of magma and fractionation.

## 2. Geological setting and studied samples

Several contrasting types of granitoid plutons (e.g., Cháb et al., 2010) of Variscan (c. 370–310 Ma) age occur within the Bohemian Massif. The selected complexes of granitic rocks (plutons) include the major types of magmas intruding during the Variscan orogeny throughout Europe. Some of the plutons comprise suites of intrusions that differ in their degrees of differentiation, e.g., in their contents of major and trace elements. Therefore, the samples studied herein combine differences resulting from the parental magma composition with the differences caused by melt fractionation, contamination, mixing, and other processes. The following representative Variscan granitoid plutons in the Bohemian Massif were collected (Fig. 1).

### 2.1. Central Bohemian Pluton

The Central Bohemian Pluton (CBP) situated in the south-central part of the Czech Republic is a composite pluton, comprising intrusive suites of different geochemical types. The most important suites are as follows (Holub et al., 1997b; Janoušek et al., 2000): (i) calc-alkaline, mostly metaluminous amphibole–biotite tonalites and quartz diorites to biotite trondhjemites and granodiorites with associated basic

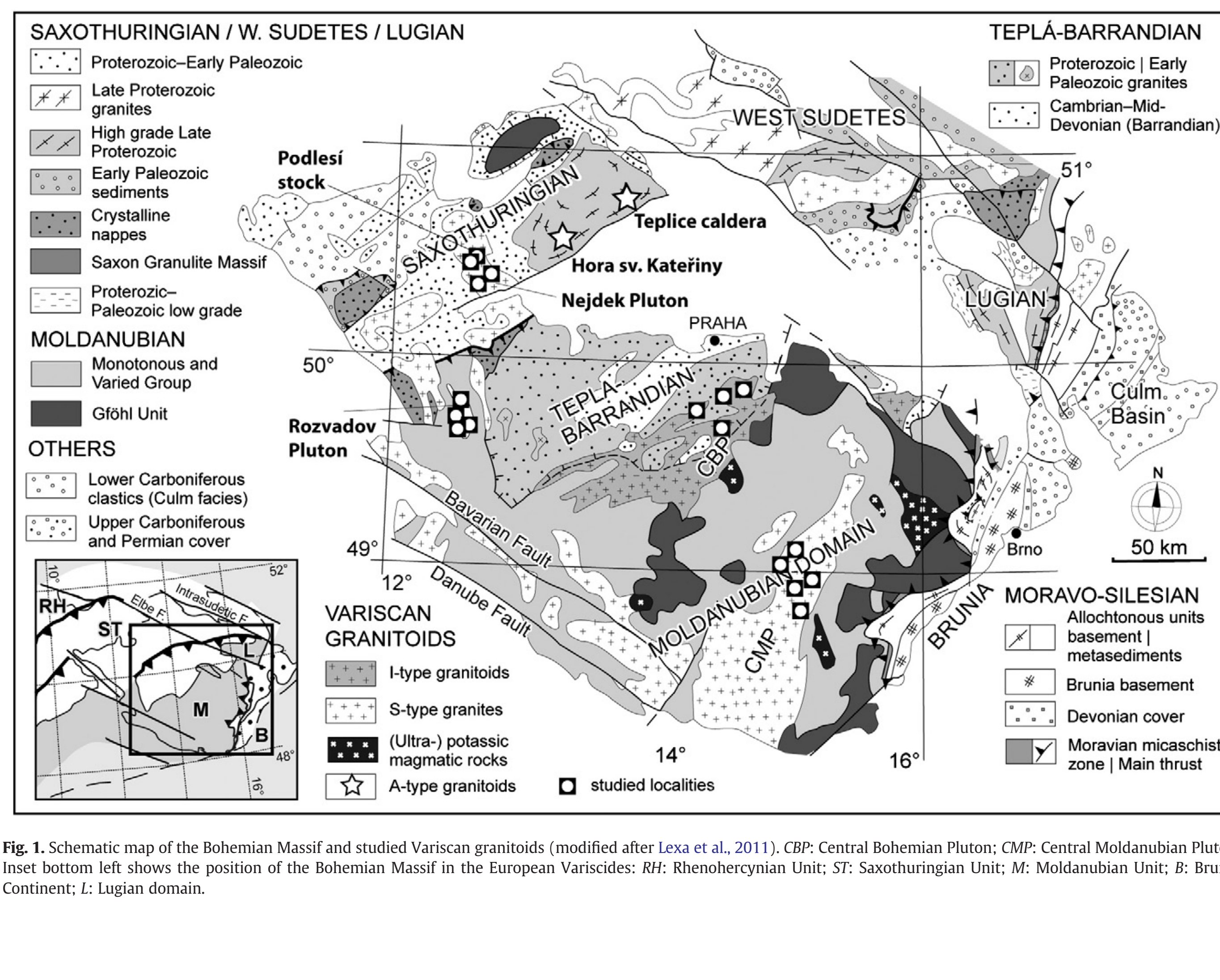


**Fig. 1.** Schematic map of the Bohemian Massif and studied Variscan granitoids (modified after Lexa et al., 2011). *CBP*: Central Bohemian Pluton; *CMP*: Central Moldanubian Pluton. Inset bottom left shows the position of the Bohemian Massif in the European Variscides: *RH*: Rhenohercynian Unit; *ST*: Saxothuringian Unit; *M*: Moldanubian Unit; *B*: Brunia Continent; *L*: Lugian domain.