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Feldspar crystallization under magma-mixing conditions shown by cathodoluminescence and geochemical modelling – a case study from the Karkonosze pluton (SW Poland)

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ABSTRACT

Feldspars from the Karkonosze pluton (SW Poland) display many features compatible with magma mixing. The mixing hypothesis has been tested using a geochemical mass balance law resulting in two possible paths of magma hybridization. Based on the results of the geochemical calculation, feldspar samples have been chosen along both mixing lines for cathodoluminescence (CL) investigation which was used as the main tool for the reconstruction of their crystallization path. Changes in the conditions of nucleation and crystallization of the feldspars as well as their movement within the magma chamber have been recognized due to different luminescence characteristics. These changes in the conditions of crystallization obtained by CL allow a precise determination of the genetic affinity of the samples to more mafic or more felsic environments.

The results of the present study proved CL to be a valuable tool for the study of crystal-growth morphologies in a dynamic, turbulent environment and also as a geochemical tool for the reconstruction of various petrogenetic mechanisms (e.g. magma hybridization). Accordingly, the combination of CL with geochemical modelling provides corresponding information about magma evolution in an open system.

KEYWORDS: cathodoluminescence, Karkonosze pluton, Poland, feldspar, magma mixing.

Introduction

MAGMA mixing/mingling implies physical and chemical interaction between melts, leading to obvious disequilibrium conditions. Disequilibrium influences the nucleation and growth rate of crystals. Hibbard (1981) recognized textures in mantled minerals, which result from growth in an un-equilibrated system. His idea has been further developed by many subsequent studies carried out especially on plagioclases from felsic rocks (e.g. Barbarin, 1990; Bussy, 1990; Wark and Stimac, 1992; Anderson and Eklund, 1994; Müller and Seltmann, 2002; Baxter and Feely, 2002; Grogan and Reavy, 2002). The evidence of magma mixing/mingling is found, in particulat, in granite bodies and can be observed over a range of scales, from whole pluton down to single crystals. The composition and growth morphology of igneous feldspars reflect certain changes in their crystallization environment. They can give a reliable record of the crystallization dynamics of the melt and its thermal and compositional turbulence (e.g. Anderson, 1984). The growth morphology is usually investigated by determining the optical properties of feldspars using polarizing microscopy (e.g. Hibbard, 1981, 1994; Baxter and Feely, 2002; Grogan and Reavy, 2002). Geochemical tools such as the electron microprobe technique also support the research on disequilibrium textures (e.g. Ginibre *et al.*, 2002). The growth of feldspars in a dynamic environment has also been studied experimentally (Wark and

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Stimac, 1992). In most cases, the research was focused on plagioclases as studies of K-feldspars are rare (Long and Luth, 1986; Vernon, 1986; Cox *et al*., 1996; Waight *et al*., 2000).

So far CL has been used only casually for the reconstruction of magma mixing/mingling processes. In actual fact, it appears to be highly suitable for the research of growth phenomena since many textures invisible in light microscopy are revealed by means of CL. In the present study we applied CL for the investigation of feldspar textures, proving its applicability for the reconstruction of the crystallization paths of feldspars under magma-mixing/mingling conditions. Furthermore, CL may provide information on the degree of magma hybridization. The luminescence of feldspar minerals is often very sensitive to such changes in the crystallization environment such as magma mixing. The trace elements incorporated in feldspars often reflect the chemical environment during their crystallization (e.g. Singer *et al*., 1995; Tepley *et al*., 2000; Ginibre *et al*., 2002), and many of these elements are effective activators in feldspars (Mora and Ramseyer, 1992; Götze *et al*., 2000). The element concentration necessary for luminescence activation can be very low, often below the detection limit of electron microprobe or other spatially resolved analytical techniques. Therefore, CL can be much more sensitive as a geochemical tool than many other analytical devices. The distribution of the trace elements and the changes in their concentration during hybridization should permit precise reconstruction of the space and time pattern of the process.

The identification and quantification of processes responsible for magma generation and evolution are realized by geochemical modelling (Rollinson, 1993). The behaviour of the elements is mostly considered in mass balance calculations. The mathematical approach to magma mixing processes shows the dependence between the degree of mixing, the composition of the melts involved in the mixing process and the composition of the hybridized melt (Rollinson, 1993; Martin, 2002).

Feldspars from the Karkonosze Massif (SW Poland) have been chosen for the present study. Rapakivi alkali feldspar megacrysts from the Karkonosze porphyritic granite are crystallized under magma mixing processes (Słaby *et al*., 2002). The combination of chemical analysis, CL and modelling was applied to obtain complex information about the entire crystallization process.

Geological setting

The Lower Carboniferous Karkonosze granite pluton belongs to the West Sudetes domain. It is located on both sides of the Polish-Czech border (Fig. 1). The domain is composed of a heterogeneous mosaic of pre-Permian basement fragments involved in the Variscides and is mostly considered a part of the Saxothuringian zone (e.g. Kossmat, 1927; Behr *et al*., 1984; Franke *et al*., 1993; Matte *et al*., 1990; Matte, 1991). The pluton is mainly estimated as a late- (Wilamowski, 1998) or post-orogenic granite pluton (Diot *et al*., 1994, 1995; Duthou *et al*., 1991), although the mode of magma generation and emplacement is still a subject of debate (see Mierzejewski, 2002, for a review). The question concerning the composition of its protolith is one of the most interesting problems, as yet unresolved. The Karkonosze pluton consists of three texturally different granite facies: a coarse- to medium-grained porphyritic facies, a medium- to fine-grained (equigranular) facies and a granophyric facies (Borkowska, 1966). Due to different modal compositions, Klominsky (1969) distinguished four types of biotite granite within the pluton – a two-mica granite, and three types of granodiorite. Although several authors point to similar geochemical features of the whole pluton (Pin *et al*., 1987, 1988; Duthou *et al*., 1991), the existing data cannot be interpreted in a unique way, especially in the case of the porphyritic granite. The Rb/Sr data of samples from two quarries located close together show initial $^{87}Sr/^{86}Sr = Sr_i$ of 0.7066 and 0.7056, respectively, with an estimated εNd_i of −3.5 (Pin *et al*., 1988; Duthou *et al*., 1991). Based on these isotopic data, the authors assume fairly primitive protoliths for the Karkonosze granite. The low Sr_i value indicates either an intracrustal magma source for the granite pluton or the admixture of a more basic component to crustal melts. The lamprophyre veins within the pluton are considered as remnants of mantle material, whereas the reworked enclaves found in porphyritic granite are assumed to be remnants of an older basic intrusion assimilated by the granite magma. According to Kennan *et al*. (1999), the low Sr_i ratio excludes gneisses from the Sudetes as potential source material of the granitic magma. The Karkonosze granite, however, shows some features of both 'S'- and 'I'-type granites (Pin *et al*., 1987; Wilamowski, 1998). Borkowska (1966) suggested different sources for the Karkonosze magma including

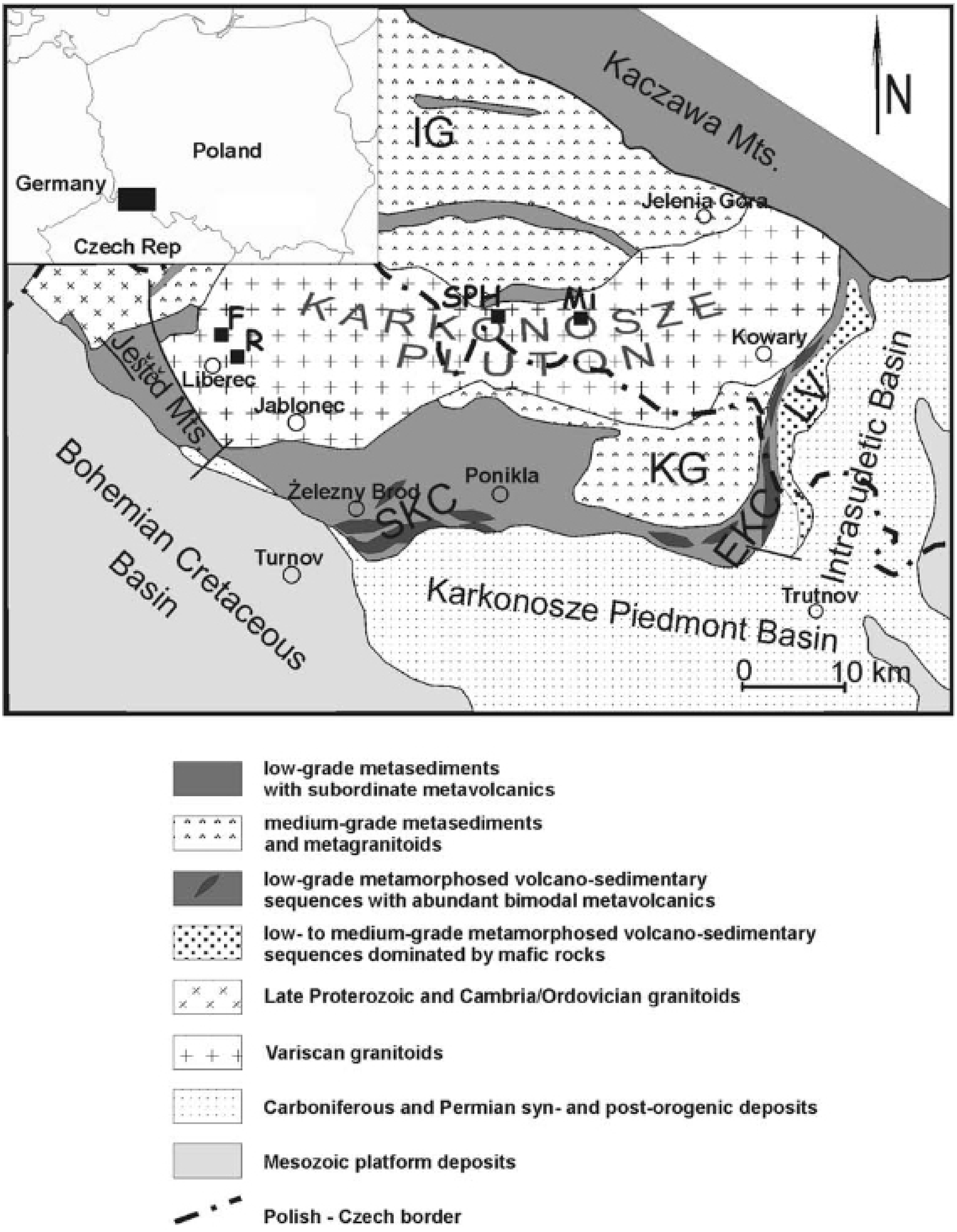

FIG. 1. Simplified geological map of the Karkonosze-Izera massif (after Patočka *et al*., 2000). IG – Izera gneisses and granito-gneisses with belts of mica schists; EKC – Eastern Karkonosze Complex; LV – Leszczyniec unit; SKC – Southern Karkonosze Complex; SPH – Szklarska Poręba Huta quarry; MI – Michałowice quarry; R – Rudolfov quarry; F – Fojtka quarry.