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# MECHANISMS OF DIFFERENTIATION OF THE KARKONOSZE GRANITE

**Abstract:** This paper presents different stages of the magmatic evolution that led to Karkonosze granite formation. Two main mechanisms played a prominent role in differentiation: 1) mixing of coeval magmas (mafic and felsic) prevailed during the early stages of pluton formation; 2) fractional crystallization mostly controlled the differentiation of the more evolved melts. The poles of mixing are assumed to be derived from partial melting of contrasted sources: a metasomatized mantle for the mafic pole and most probably a lower crust for the felsic pole.

**Keywords:** fractional crystallization, mixing-mingling, magma source, Karkonosze, Variscan granite

## INTRODUCTION

Lower Carboniferous Karkonosze granite pluton is emplaced into the central part of the Karkonosze-Izera unit (Northern extremity of Bohemian Massif, SW Poland – NW Czech Republic). Structural studies by Diot *et al.* (1995) revealed, that it emplaced shortly after magma generation, probably during the extensional collapse, that corresponds to the final phase of the $D_2$ deformation in West Sudetes. The petrogenesis and source of the granite has been subject to controversies and discussions that can be grouped into two categories: 1) Borkowska (1966) proposed that the protolith consisted of crustal rocks metamorphosed under amphibolite facies conditions; 2) based on isotope investigations, Duthou *et al.* (1991) assumed a fairly primitive crustal source for granitic melt. Słaby *et al.* (2003) and Słaby, Götze (2004) first recognized that Kakonosze granite differentiation proceeded through two distinct mechanisms: mixing and fractional crystallization. Their study was mainly based on reconstruction of feldspar crystallization paths.

## GRANITE FACIES

Karkonosze pluton is biotite granite that forms three main facies whose terminology is given in table 1. The porphyritic granite is the wider spread facies. It is also the oldest one, that has been dated by $^{40}$Ar/$^{39}$Ar method at 320 ± 2 Ma (Marheine *et al.* 2002). The same author obtained an age of 315±2 Ma on both the medium and fine grained facies. It must also be noted, that a two mica granite located at the S and SW edge of the pluton gave a similar age. However, the two mica granite is not cogenetic with the rest of the pluton and consequently, it will not be considered in this paper. In many places the porphyriticgranite contains abundant microgranular-mafic-enclaves and is cross cut by both syn-plutonic (composite) and late (mafic) dikes (Barbarin 2005); all are lamprophyric to granodioritic in

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Table 1 Comparative terminology used to describe Karkonosze granite facies.

| **This paper** | **(Borkowska, 1966)** | **(Klominsky, 1969)** |
|---|---|---|
| porphyritic | central type | Jizera type |
| medium grained | central type | Liberec type |
| fine grained | ridge type | |

composition. In most of these places field relationships such as progressive contacts, ocellae, mantled feldspars, feldspars mechanically introduced into mafic enclaves or dykes, demonstrate interactions between two magmas as well as hybridization. Contrarily to porphyritic facies, medium grained granite only contains very few mafic-microgranular-enclaves whereas fine grained facies is enclave free.

## FRACTIONAL CRYSTALLIZATION

The porphyritic granite is very rich in K-feldspars phenocrysts and some outcrops display evidences of accumulation of these crystals. In fact, K-feldspars not only crystallized as phenocrysts but also into the matrix. Phenocrysts are zoned, thus indicating that they recorded changes in magma composition. On the other hand, the abundance of phenocrysts is negatively correlated with $SiO_2$ (and positively with MgO) such that it is concluded that phenocryst abundance decreases with differentiation. In other words, the phenocryst-free silica-rich granites are considered as representative of evolved magmas, differentiated through fractional crystallization. In Harker's diagrams, the whole fine grained granite as well as the $SiO_2$-richer (>71%) porphyritic granites show a single trend of differentiation that we interpret in terms of fractional crystallization. It must be noted that if medium grained granite does not define a real trend, all samples fall on the trend of fine grained and evolved porphyritic granites.

A model of simple fractional crystallization has been tested; it is based on a double approach. First the composition of the cumulative assemblage has been calculated using a simple mass-balance algorithm (Störmer, Nicholls 1978). In a second stage, the results of major element calculation have been reintroduced in trace element modelling using the classical Rayleigh (1896) law. Major elements indicate that it is possible to explain the whole differentiation from $SiO_2 = 71\%$ until $SiO_2 = 78\%$ by removing 25% of a cumulate made up of 63% plagioclase, 34% biotite, 2% apatite and 1% K-feldspar. Trace element modelling is consistent with this result and in addition it indicates that small amounts of accessory phases played a significant role. The calculated amount of accessory phase is about 1% zircon and 0.5% allanite.

The results of modelling are consistent with petrographic and mineralogical observations; they demonstrate that fractional crystallization played an important role during Karkonosze differentiation, and that it has been prominent in the more evolved magmas. Evidences of fractional crystallization are also recorded into K-feldspar whereas, paradoxically, modelling predicts only insignificant K-feldspar fractionation. One of the possible explanations is that these minerals crystallized into the magma but that they were not efficiently removed, may be due to their relatively low density quite similar to magma density, or to the high viscosity of the silica-rich magma.

## MIXING-MINGLING

One of the characteristics of porphyritic granite is that it is rich in mafic-microgranular-enclaves. Obviously mafic and felsic magmas interacted, as recorded by feldspar chemical composition, growth morphology and in some places by mantled textures (Słaby *et al.* 2003; Słaby, Götze 2004). When enclave compositions are plotted in Harker diagrams they define a trend different of the fractional crystallization trend evidenced in the silica-rich granites; which clearly indicates that some kind of hybridization took place between a mafic magma and the granite. This is well exemplified by large hybridization zones found within porphyritic granite (Słaby, Götze 2004); there hybrids define a trend that points towards lamprophyre composition, thus indicating that lamprophyres could be one pole of mixing with granitic magma. This is well exemplified with major elements, for instance in the $Al_2O_3$ vs. $SiO_2$ plot or better in a $(Na_2O+K_2O)/CaO$ vs. $Al_2O_3$. Modelling mainly based on REE corroborates this interpretation. However, it must be noted that lamprophyric magmas mixed with granitic magma not only early in its history, but that this process extended through the whole crystallization history as well. This is shown by microgranular-mafic-enclaves, syn-plutonic dikes (composite) but also by late dikes (mafic) whose chilled margins demonstrate that lamprophyric input continued even when granite was almost solid. In addition, few enclaves and composite dikes define a different trend that does not evolve towards lamprophyric compositions. These hybrids are Al, Fe-richer and Mg and Ca-poorer than the “classical” ones, with lamprophyre affinity. This should reveal that lamprophyres were not the only mantle derived magmas implied in Karkonosze granite formation, but that another mantle source, slightly different in composition, was also active. If the effects of magma hybridization are obvious in microgranular-mafic-enclaves, they are also visible in porphyritic granite. Of course in this latter, due to huge volumetric differences (granite/enclave ratio), the effect is more discrete, but for instance diagrams such as $(Na_2O+K_2O)/CaO$ vs. $Al_2O_3$ clearly show that most of porphyritic granites are hybridized whereas this mechanism has almost no influence on fine grained granite composition, which is enclave free.

## MAGMA SOURCE

Isotopic data show a scattering of $^{87}Sr/^{86}Sr$ which makes them difficult to use and to interpret. $\varepsilon_{Nd}$ (320) shows more coherent behaviour, with low values for porphyritic granite (-7 to -4); higher for granodioritic hybrids (-4 to -3) and even greater for lamprophyres (-2 to -1), thus being coherent with the assumption of mixing between granite and lamprophyre. The low $\varepsilon_{Nd}$ in porphyritic granite are evidence of its derivation from a crustal source, however, even the poorly contaminated mafic magmas (lamprophyre dykes) possess negative $\varepsilon_{Nd}$ which points towards an enriched mantle source; source that must be LILE-rich. On the other hand, the Karkonosze granite is not alumina oversaturated and does not contain cordierite or muscovite (with exception of the marginal two mica type), consequently, it does not belong to S-type granites: a purely sedimentary source must be precluded. The more realistic assumption should be that both mantle and crustal sources are implied in Karkonosze granite genesis: an enriched mantle and a continental crust. A point that remains unclear is the genetic link between these two magmatisms. As they both took place at the same place and at the same moment, we propose that a genetic link existed between them. This link could be that the emplacement of mantle derived magmas into or under (underplating) the lower crust could have provided additional heat such that crust melting becomes possible.

The LILE–rich character as well as the slightly negative $\varepsilon_{Nd}$, of the mantle derived lamprophyres indicates that the mantle source itself was enriched. Blusztajn, Shimizu (1994) envisaged the possibility of a carbonatitic metasomatism, however, due to the lack of Sr enrichment and to the high Ti/Eu ratio, this hypothesis must be discarded. On the other hand, Karkonosze granite is located in a collisional suture that before acted as a subduction such that a subduction-like metasomatism can be suspected. Indeed, in such an environment the mantle wedge is subjected to strong metasomatism either by fluids or melts coming from the subducted slab. Melts generated by basalt slab melting are Na-rich, and K-, Rb- and HREE-poor (adakites; Martin *et al.* 2005). These characteristics are not consistent with lamprophyre composition. Fluids produced by dehydration of the subducted slab (sediments and/or hydrated basalts) result in an enrichment of the mantle, mainly in LILE but also give rise to a negative Nb anomaly. The calculated mantle source for lamprophyres shows these characteristics. Of course, the arguments developed in this discussion are not definitive, and for instance an alkaline melt could also have been metasomatic agent, but the origin of such an alkaline melt appears as unusual and improbable in a subduction environment.

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