

Cathodoluminescence (CL) of apatite as an insight into magma mixing in the granitoid pluton of Karkonosze, Poland

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Cathodoluminescence is a powerful analysis tool, providing detailed information about crystal growth and hence the dynamics of the system from which a crystal formed. Many magmatic minerals exhibit characteristic luminescence due to the presence of certain structural defects such as trace element impurities or vacancies, therefore may record even subtle changes in the chemical composition of the melt. Apatite is one of the most abundant accessory minerals in magmatic rocks and due to its early appearance and long stability during the differentiation of magma, it can preserve information about magmatic and post-magmatic processes. Intensive luminescence of apatite, activated mostly by trace elements such as REE³⁺ and Mn²⁺, allows us to observe the internal structure with all its smallest details. This is most advantageous when apatite demonstrates very complex, internal zoning resulting e.g. from magma mixing.

A perfect example of magma mixing processes can be observed in the composite granitoid pluton of Karkonosze, Poland, where the effect of mantle- and crust-derived melt hybridization is seen both in macro-scale (magmatic enclaves) and micro-scale (complex zonation patterns in minerals, e.g. apatite). The mixing model, including subsequent stages of magma mixing ± fractional crystallization, has been created based on whole-rock and mineral chemistry, growth texture and CL (Słaby & Götze, 2004; Słaby & Martin, 2008). This study concentrates on apatite which chemistry is particularly sensitive to changes both magmatic mass as well as hydrothermal environment.

Apatite from the granodiorites – most primitive rocks with the highest proportions of the mafic vs. felsic melt – demonstrate very complex zoning revealing subtle to drastic changes in melt composition during crystal growth (Fig. 1a,b). More apatite grains exhibit violet luminescence activated by Sm³⁺, Dy³⁺ and Nd³⁺, however the relative intensity of the peaks is higher for the zones with yellow luminescence (Fig. 2a). In comparison to the more evolved rocks, the intensity of the REE peaks is the highest (Fig. 2c). Such strong activation by REEs is in agreement with the whole rock and apatite composition which are enriched in these trace elements.

After the early mixing, mafic and felsic melts take separate paths and mix only occasionally giving first microgranular magmatic enclaves and later composite dykes, both enclosed in porphyritic evolved granite. Apatite from the enclaves is more homogeneous than in the primitive rocks and shows most often only yellow luminescence (Fig. 1c). The intensities of the REE³⁺ and Mn²⁺ peaks are considerably lower for both violet and yellow luminescence. Apatite from the porphyritic host granite shows various textures, from oscillatory and irregularly zoned to almost homogeneous. Along with the differentiation progress, the luminescence of apatite turns from more violet to more yellow, with the apatite from the less evolved granite having higher intensity of the REE³⁺ bands and the apatite from the more evolved granite having a more pronounced Mn²⁺ peak (Fig. 2b). This is consistent with the apatite composition showing progressive depletion in REE-content from less to more evolved porphyritic granite.

Apatite from the last and the youngest influx of the mafic melt – the composite dykes – demonstrates again more complex zonation patterns. Often the grains contain irregular marginal zones showing strong yellow luminescence which can be associated with fluid alteration

documented in these rocks (Fig. 1d). The intensity of REE³⁺ and Mn²⁺ bands is distinctly lower than in the apatites from earlier described rocks.

Whereas the porphyritic granite may contain a small portion of mafic melt dissolved in the granitic magma, in the upper part of the pluton we can find a pure, crust-derived equigranular granite. Apatite from this rock is oscillatory zoned or homogenous and shows mostly only yellow luminescence. The spectrum exhibits the lowest intensity of the activated bands and the most pronounced Mn²⁺ peak (Fig. 2c).

In general cathodoluminescence characteristics of apatites agree well with the whole rock chemistry and the mixing scenario. Early magmatic stages dominated by mixing gave apatite with violet luminescence characteristic for more alkaline melts. Grains with complex zonation patterns showing violet and yellow luminescence represent heterogeneous environment of mixed mantle-derived, more alkaline melt with crustal, more acidic magma. During the differentiation there is a progressive decrease in REE-content (indicated by the decreasing intensity of the spectra, Fig. 2c) of apatites which in more evolved rocks exhibit mostly yellow luminescence typical for granitic, acidic melt. In rocks infiltrated by fluids, cathodoluminescence is helpful in recognizing altered parts of apatite with strong yellow luminescence. This study shows that cathodoluminescence is an important tool for recognizing magmatic processes such as magma mixing and its application should be complementary to other methods in order to fully understand the dynamics of heterogeneous systems in micro-scale.

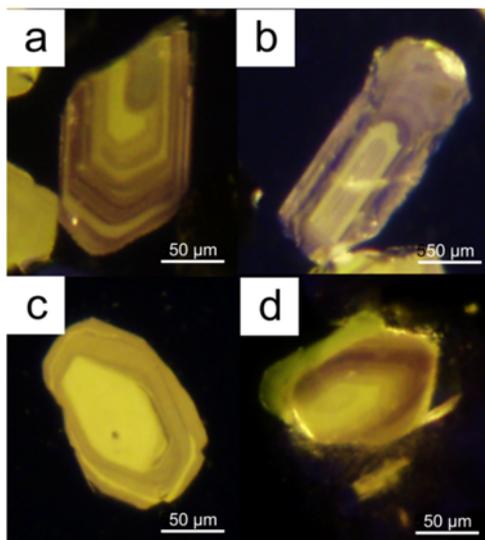


Fig.1. CL images of apatite grains. a,b- strongly zoned apatites from granodiorites; c- homogenous, yellow luminescent apatite with from the magmatic enclave; d- zoned apatite with a late, yellow-green CL rim associated to fluid alteration from the composite dyke.

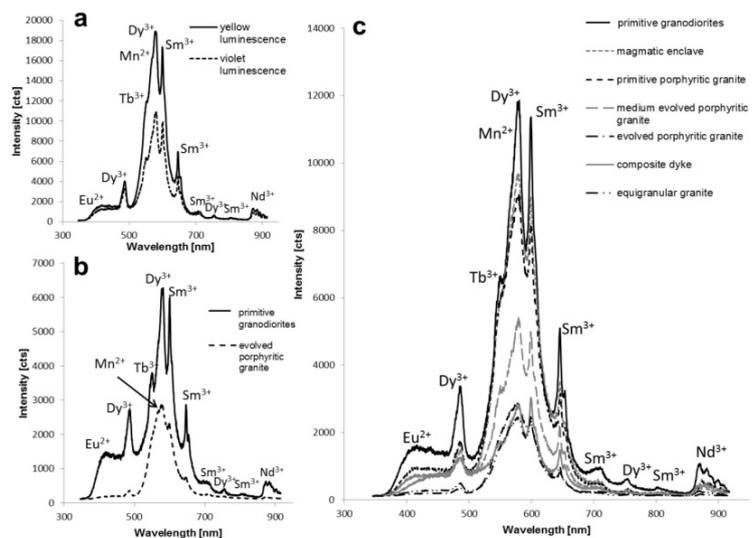


Fig.2. Representative CL spectra. a – violet and yellow luminescent apatite from the most primitive granodiorites; b – violet emitting apatite from primitive granodiorites (more pronounced REE³⁺) and evolved porphyritic granite (pronounced Mn²⁺); c – combined spectra of violet luminescence of the apatites from all types of rocks, indicating inverse correlation of Mn²⁺ vs. REE³⁺ emissions..

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References:

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