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Determination of the degree of compositional disorder in magmatic enclaves using SEM X-ray element maps

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Abstract: Mafic Microgranular Enclaves (MME) are commonly observed in mixed/mingled rocks in intrusive calc-alkaline suites. Analysis of MME from the Sithonia Plutonic Complex (Northern Greece) was carried out using a new method, based on the acquisition of X-ray maps of chemical elements within enclave thin sections, and by calculating the degree of compositional disorder (*S*) attained by enclaves during magma interactions. Results show that the compositional disorder of MME is linearly correlated with the geochemical evidence of magma mixing (*e.g.* the variation of CaO in MME) during the first stages of the magma interaction process. As the intensity of magma interaction increases, *S* stabilises toward an asymptotic constant value. In addition, the degree of compositional disorder for the different chemical elements increases at different rates for the same degree of magma mixing.

We suggest that *S* depends on the different paths of geochemical evolution of MME, and that it is related to the infiltration of portions of felsic magma, within MME, that provoke increasing degrees of dilution of the enclave mafic magma. This process is simulated using a chaotic dynamical system in which the dispersal of felsic magma occurs within the enclave mafic magna. As observed in natural rocks, the degree of compositional disorder of the simulated systems increases linearly during the first steps of the process and, as the mixing intensity increases, stabilises towards an asymptotic constant value. The greater the contrast in content of chemical elements between the felsic and the mafic magma the faster *S* changes. This result can explain the different rates of increase of the parameter *S* for the different chemical elements observed in natural MME.

The method utilised to estimate *S* for MME is a useful technique that provides information on the degree of mixing exhibited by mafic microgranular enclaves. Such information, integrated with more conventional petrological techniques, can lead to a better understanding of mixing processes between felsic and mafic magmas.

The method has many potential applications in petrology since it is robust and can be used for accurate and reliable investigations of the degree of homogeneity of rock samples and permits fast detailed analyses of sample areas, taking into account the spatial relationships among the phases constituting the sample.

Key-words: microgranular mafic enclaves, magma mixing, X-ray maps, degree of compositional disorder, chaotic dynamics.

Introduction

Magmatic interaction processes have been recognized and studied in both the plutonic and volcanic environments (*e.g.* Thomas & Tait, 1997; Blake & Fink, 2000; Poli *et al*., 1996; DeRosa *et al*., 1996). Most calc-alkaline plutons in orogenic belts contain mafic microgranular enclaves (hereafter MME; see Didier & Barbarin, 1991 for definition and overview) as a common feature, and it is widely accepted that they are the result of mingling and mixing processes between mafic and felsic magmas (*e.g.* Williams & Tobish, 1994; Poli *et al*., 1996; Flinders & Clemens, 1996).

In this paper, we propose a method for estimating the degree of compositional disorder (*S*) attained by MME during magmatic interaction processes using X-ray maps of chemical elements collected on thin sections of enclave samples. The aim of this study is to explore the possibility of using such an approach as an additional petrological tool that may provide a better understanding of magma mixing processes.

MME from the Sithonia Plutonic Complex (Greece)

The studied MME (Fig. 1) occur in the granodioritic bodies that make up part of the Sithonia Plutonic Complex (Northern Greece). These enclaves are studied because they have been accurately analysed from the petrographical and geochemical points of view (Christofides *et al*., 1990; D'Amico *et al*., 1990; Perugini *et al*., 2003) and are therefore suitable for exploring other methodological approaches.

Studied MME range in size from 10.0 to 130.0 cm^3 (Perugini *et al*., 2003); they show a very homogeneous fine grained texture (average grain size is about 0.1 mm). The average modal proportions (in vol.%) of minerals forming MME are as follows: Qtz (15), Kfs (8), Pl (30), Bt (28), ± Hb (4), Ep (5), accessories (5). Plagioclase, subhedral to anhedral, commonly shows normal zoning. K-feldspar is scarce and typically occurs as poikilitic anhedral crystals. The same textural relationships are observed for quartz,

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