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Unravelling the interaction dynamics of a carbonatite-silicate magmatic pair: A numerical approach based on Korteweg Stress theory

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Most of the worldwide carbonatites occur in spatial association with silicate rocks. Even when unquestionable evidence for the associated carbonatite and silicate rocks to represent contemporaneous liquids exists, the modes of interaction between the two liquids can be difficult to infer.
In general, the retrieval of information about the mechanisms of interaction between magmas can be complicated by the intrinsic dynamical nature of such systems. The development of new physico-chemical equilibria (e.g. hybridization) can erase any information about the previous stages of interaction. However, the occurrence of magmatic heterogeneities, such as enclaves and flow bands, as well as mineral disequilibrium textures, may serve as dynamic markers for the underlying interaction processes. Small-scale heterogeneities, in the form of micron to millimetre sized globules, characterized by more or less smooth interfaces, are frequently observed in carbonatite-silicate pairs. Textural observation, as well as the lack of suitable mechanisms for the dispersion of a discrete magmatic liquid in the form of a small-scale emulsion, have lead many petrologists to advocate immiscible separation as the process capable of forming such textures. However, the geochemical criteria for liquid immiscibility are not always met, and when not coupled with geochemical and dynamical arguments, textural observation may lead to ambiguous conclusions.
In this study we adopted an integrated approach in order to infer the details of magmatic interaction of a carbonatite-silicate pair from Massif Central (France). The studied samples display emulsion-like textures, formed by micro-scale dolomitic globules dispersed in a trachytic glassy matrix. Our approach is based on a novel numerical method, coupled with textural observation and geochemical analyses. The novelty of our numerical model consists in the inclusion, in the adopted advection-diffusion equations, of a term that takes into account the effect of gradient stresses (namely Korteweg Stress). The theory of Korteweg stress predicts that a transient surface tension may arise at the interface of two miscible liquids characterized by significant rheological differences. The results of our computer simulations show that globular textures with smooth interfaces may develop in miscible magmatic liquids as a consequence of processes of drop relaxation, breakup and coalescence, driven by Korteweg stresses. Such processes are analogous to those observed for immiscible liquids.
In order to validate our assumption that the interfaces between the melts are diffusive (i.e. the liquids are miscible) we performed a series of EPMA analyses on our natural samples. The results of our analyses show that diffusion gradients exist between the carbonatite and silicate fraction, and disequilibrium features, such as resorption surfaces, can be detected in the elemental X maps.
The results of our investigations suggest that globular textures may be generated in miscible magmatic liquids characterized by a strong rheological contrast. Therefore, the occurrence of such globules in carbonatite-silicate pairs, and in general in igneous rocks, should be regarded as circumstantial rather than absolute evidence of thermodynamic immiscibility.