

Pattern formation in a mineral - fluid system

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This paper will discuss the origin of periodic non-equilibrium textures in rocks as a problem of pattern formation in a mineral - fluid system.

1. Why non-equilibrium textures?

The non-equilibrium textures in rocks include a lot of information on crystallization, chemical reaction, and heat and mass transfer, therefore they are very important to understand the process of rock formation.

2. What is a mineral - fluid system?

Most processes in the rock formation involve interactions between minerals and fluids. Examples are 1) crystallization of minerals from magma, and 2) metamorphic reactions catalyzed by interstitial fluids. Coupling of these interactions can cause various textures in rocks. Thus the rock under its formation can be regarded as a mineral-fluid system.

3. Why periodic textures?

Among various textures in rocks periodic textures have attracted and bothered petrologists as a universal and pathological case difficult to understand. The most universal examples are igneous and metamorphic layerings. Recent developments in the theory of dissipative structures and that of reaction - diffusion systems provoke a modeling of these periodic textures as a problem of pattern formation in a non-equilibrium open system.

4. Intrinsic problems in a mineral - fluid system not involved in existing theories

Straightforward application of existing theories to pattern formation in a mineral - fluid system fails. For example, Belousov - Zhabotinsky reaction (BZ reaction) is a representative model of pattern formation in reaction - diffusion systems, however, the principal mechanism of BZ reaction, the autocatalytic reaction, rarely occurs in inorganic systems like rocks. Also heat transfer will be an important factor in case of periodic textures in magmatic systems, which has not been considered in the theory of reaction - diffusion systems.

Some mechanism for material to concentrate will be necessary for the formation of the periodic textures. With emphasis on the mechanism, I present below several models describing pattern formation in a mineral - fluid system under the condition that the fluid is static.

5. Importance of uphill diffusion in a mineral - fluid system

This paper notices the importance of uphill diffusion as a potential mechanism for material to concentrate in a particular place in a mineral - fluid system. Uphill diffusion commonly occurs in multi-component silicate melts (Nishiyama, 1998). Uphill diffusion can be driven by several different mechanisms also in a mineral - fluid system as will be described below.

1) Uphill diffusion due to local equilibrium (Gibbs - Duhem relation)

Local equilibrium in a mineral - fluid system requires that diffusion in a fluid should satisfy Gibbs - Duhem relation for coexisting minerals, unless the minerals will become unstable with respect to diffusion. This requirement causes uphill diffusion in a fluid. Nishiyama (1994) presented a model of metamorphic layering due to uphill diffusion of this type.

2) Uphill diffusion due to electrical neutrality condition

In ionic solutions diffusion should satisfy electrical neutrality condition. This paper presents a model in which uphill diffusion due to electrical neutrality may play an essential role in the supersaturation theory of Liesegang rings.

6. New model of igneous layering

This paper describes an example of igneous layering (Bilibili layered intrusion) which satisfies a spacing law analogous to that of Liesegang rings. Each layer in this particular layering represents a mushy layer (a melt layer with a lot of crystals) formed at the wall of the intrusive during the solidification. Chemical fractionation in the mushy layer may have been caused by diffusion - controlled nucleation and growth due to diffusion much faster than heat transfer.