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The geometry of phase mixing: inferring viscous deformation processes from quantitative spatial distributions

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Creep in silicates and ice largely occurs by two different deformation mechanisms: Dislocation creep and diffusion creep (including grain boundary sliding). The distinction between the two mechanisms is of primary importance for all rheological studies from mantle to surface conditions. In addition to commonly used methods like crystallographic preferred orientation (CPO) and dynamic recrystallization microstructures, the spatial distribution of phases can be a powerful criterion for distinguishing deformation mechanisms.
Dynamic recrystallization in dislocation creep modifies existing microstructures, which dominantly consist of a single phase (apart from small amounts of second phase particles). The microstructures resulting from dislocation creep typically develop phase segregations into layers. Conversely, diffusion creep commonly involve neighbor switching and, when involving changes in phase composition or chemical reactions, nucleation of new phases. Grains of one phase may nucleate and grow between grains of other phases. The resulting phase mixtures may be distinguished from dislocation creep microstructures by their spatial phase distribution. This may be particularly important when large amounts of second phase particles present a transition between the deformation mechanisms. The phase distribution may form "random", "clustered" or "anticlustered" patterns. As an example, a large dataset from an eclogite of the Troms Nappe (Caledonides, Norway) displaying random and non-random 2-D geometries is compared to results from 3-D numerical modeling. Starting with the Markov Chain analysis by Kretz (1970) we formulated two models for random spatial distributions: one based on the relative amount of grain boundary surface (surface model) and one based on the relative volume fraction of each phase (volume model). In both cases, if the aggregate consists of two phases (A and B), the relative amounts of grain contacts (AA, BB and AB) follow a binomial distribution. Because of the different grain sizes of the two phases involved, the eclogites are evaluated using the surface model. It can be shown that their microstructures deviate from spatial random distributions showing various degrees of anticlustering and in many cases.

A more general model for random distribution considers only one phase (A) and two types of grain contacts (AA and AB, where B is the "matrix"). This model is based on fragmenting a cluster of grains into smaller clusters. It predicts the most probable distribution of cluster sizes and the probability for contact types AA and AB. Comparison of the three models for random spatial distribution of grains shows that the discrimination of random from non-random patterns and the associated statistics depend strongly on the assumptions concerning the nature of the underlying physical process, which, in conjunction with other criteria, can be inferred from such an analysis.