KINETIC MODELLING OF GRAIN GROWTH IN PERIDOTITE SYSTEM: AN EXPERIMENTAL APPROACH

MONICA SEGATA
Dipartimento di Scienze della Terra "A. Desio", Università di Milano, Via Botticelli 23, I-20133 Milano

Mantle rheology is strongly controlled by textural features: grain size and grain growth rates affect viscosity, fluid permeability and seismic velocities. The study of the textural evolution as a function of pressure, temperature and kinetic mechanisms via experimental simulations is crucial for the understanding of mantle dynamics in a variety of geological environments.

Several grain growth studies have been conducted for monomineralic rocks in order to investigate the kinetics of the annealing process [*e.g.* olivine: Faul & Scott (2006), Nichols & Mackwell (1991), Karato (1989)]. Only recently, a bimineralic system has been inspected by Ohuchi & Nakamura (2007). These authors have suggested that the variation in modal proportions drastically affects the grain growth of the major phase due to the pinning effect of the second phase. To unravel the effect of a finely dispersed aluminous phase (spinel, plagioclase) on textural evolution of peridotites is therefore of fundamental importance to properly define the rheological behaviour of the Earth's upper mantle rocks.

Time-resolved piston cylinder experiments have been performed on peridotite compositions in the chemical system CaO-Na_2O-FeO-MgO-Al_2O_3-SiO_2-Cr_2O_3-TiO_2. Grain growth experiments have been performed using a single stage piston cylinder apparatus. Temperature conditions range from 1000 to 1100°C, pressure from 0.5 to 1.0 GPa, combined in order to achieve three different PT conditions, within both the plagioclase and spinel stability field. All the runs have been carried out under nominally dry condition. In order to evaluate the textural evolution, run durations from 10^3 to 10^6 seconds have been considered. Run products have been characterized by X-ray powder diffraction (at a synchrotron beam, ESRF, Grenoble), TEM images and by EDS/WDS microprobe. In order to enhance grain boundaries and allow a quantitative grain size analysis of all phases in the quenched run products, a chemical etching has been performed on polished surfaces. Treated samples have been carefully inspected by BSE images and elementary X-ray maps. A quantitative textural analysis has been performed by image processing technique on high resolution BSE images. The grain boundaries have been automatically detected via a complex image processing procedure based on gradient filtering.

Weight proportions of the mineral phases obtained by powder X-ray diffraction (olivine 55 wt.%, orthopyroxene 30 wt.%, clinopyroxene 15 wt.%) are in agreement with observations in natural peridotites and do not show any dependence on time suggesting that nucleation occurs at the very beginning of the synthesis and that the main time dependent process involves a textural rearrangement only.

Run products show a different textural evolution as they developed in the spinel or in the plagioclase stability field: the spinel-bearing assemblage of the longest run (10^6 seconds) is characterized by polygonal aggregates of orthopyroxene, clinopyroxene, olivine and spinel while plagioclase bearing experiments show a framework of the major phases with interstitial plagioclase.

The average grain sizes of olivine, orthopyroxene, clinopyroxene and spinel have been measured at $10^{5.5}$, $10^{5.9}$ and 10^6 in the spinel bearing experiments. Because the texture in the 10^3 and 10^4 sec runs is not observable at the SEM scale, TEM investigations have been alternatively used to characterize the average grain size of all phases. The data obtained fit the grain growth low $D^n = kt$, where D is the average grain size, *k* is a constant, t is time and n an empirical constant which value gives information about the limiting process of grain growth. The spinel (n = 3) follows a growth process of diffusion controlled growth type, while olivine, clinopyroxene and orthopyroxene (n = 3.6-3.8) follow a growth process of second phase controlled growth type. The spinel, due to his dimensional and spatial distribution, is the phase responsible for the control of the grain growth of the major phases according to a pinning process of the grain boundary. The phase whose growth resulted more inhibited is the orthopyroxene.

The growth laws obtained for olivine, orthopyroxene, clinopyroxene and spinel allowed extrapolating the average dimension values of these phases on a geologic time scale. The experimental data are comparable with the dimensions observed on natural peridotites, and are completely consistent with the experimental data reported in literature [Faul & Scott (2006); Ohuchi &Nakamura (2007)].

Both spinel grain size and spinel spatial distribution change significantly with time. In shorter runs spinel presents a bimodal grain size distribution: 1) fine dispersed grains clustered distributed; 2) relatively large grains randomly distributed. The major phases follow the same bimodal distribution suggesting a pinning effect on grain boundaries by the fine-dispersed spinel grains. Orthopyroxene in particular is present as small grains spatially associated with the fine dispersed spinel grains and as porphyroblasts near the randomly distributed spinel grains. In the longest run (10^6 seconds) spinel grains and consequently major phases grains lose this dimensional and spatial bimodal distributions. Moreover the abundance of spinel inclusion in orthopyroxene porphyroblasts increases with the increase of run durations.

The Crystal Size Distributions of spinels have slopes that decrease with time and rotate about a point characteristic of each phase: 3.5 μm for olivine, 3 μm for clinopyroxene and 2.5 μm for spinel, revealing, on the other hand, a ripening process: crystals smaller than this value are reabsorbed to promote the coarsening of large crystals in agreement with the Communicating Neighbours theory (De Hoff, 1991). The analysis of CSDs obtained for the orthopyroxene confirms the presence of two populations of grains, which have been involved in different kinetic evolution: the matrix grains and the porphyroblasts. The matrix represents the state of stagnation of the growth of the orthopyroxene due to the pinning process of the spinel on the grain boundary, while the porphyroblasts are the product of an abnormal grain growth (AGG) process as growth resumed after the pinned state.

The grain growth of the mineral phases in the peridotite systems investigated is the result of the competition between the coarsening process of the phases and the pinning process of the grain boundary by the stable aluminous phase. The dimensional and spatial distribution of the aluminous phase can determine, depending on his spatial heterogeneity, stagnation process of the growth or AGG of the major phases. The predominance of the first or the second process can cause important differences in the grain size of the peridotites with important implication on the rhelogical properties of Earth’s mantle.

REFERENCES

De Hoff, R.T. (1991): A geometrically general theory of diffusion controlled coarsening. *Acta Metall. Mater.*, **39**, 2349-2360.

Faul, U.H. & Scott, D. (2006): Grain growth in partially molten olivine aggregates. *Contrib. Mineral. Petrol.*, **151**, 101-111.

Hassold, G.N. & Srolovitz, D.J. (1995): Computer simulation of grain growth with mobile particles. *Scripta Metall*., **32**, 1541-1547.

Karato, S. (1989): Grains growth kinetics in olivine aggregates, *Tectonophys.,* **104**, 155-176.

Nichols, S.J. & Mackwell, S.J. (1991): Grain growth in porous olivine aggregates. *Phys. Chem. Minerals*, **18**, 269-278.

Ohuchi, T. & Nakamura, M. (2007): Grain growth in the forsterite-diopside system. *Phys. Earth Planet. Int.*, **160**, 1-21.