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Diffusion-controlled growth of forsterite and enstatite double layer between periclase and quartz: determination of MgO diffusion in forsterite and enstatite grain boundaries

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We investigated the solid-state reaction between periclase (MgO) and quartz (SiO_2) that produces forsterite (Mg_2SiO_4) and enstatite ($MgSiO_3$) according to:

$$\text{periclase} + \nu \text{ quartz} = (1-\nu) \text{ forsterite} + (2\nu-1) \text{ enstatite}$$

Most of the diffusion-reaction experiments were done in a piston-cylinder apparatus at 1.5 GPa pressure, for temperatures and durations ranging from 1100 to 1400 °C and from less than 1 hour to 3 days respectively. Samples were made of single crystals of periclase and quartz put into contact in platinum capsule. A thin film of platinum was previously deposited on quartz crystals to act as inert marker. No water was added and Al_2O_3 was used as pressure medium around the capsule. Experiments resulted in the formation of two monomineralic and polycrystalline layers of forsterite and enstatite according to the sequence:

periclase | forsterite | enstatite | quartz

The reaction, and especially the proportion of forsterite and enstatite produced (that is related to the stoichiometric coefficient ν), can theoritically be controlled by the diffusion of SiO_2 from quartz and that of MgO from periclase in the grain boundaries of the forsterite and enstatite layers. Because the platinum markers are always found at the periclase-forsterite interface and because of microtextural evidences, SiO_2 appears to be immobile. The reaction is thus controlled by the diffusion of MgO. In this case, the three partial reactions are

- at periclase-forsterite interface: periclase is dissolved, MgO diffuses towards quartz

$$\text{periclase} = \text{MgO}$$

- at forsterite-enstatite interface: part of the MgO flux reacts with enstatite to produce forsterite

$$(1-\nu) \text{ MgO} + (1-\nu) \text{ enstatite} = (1-\nu) \text{ forsterite}$$

- at enstatite-quartz interface: the rest of MgO reacts with quartz to produce enstatite

$$\nu \text{ MgO} + \nu \text{ quartz} = \nu \text{ enstatite}$$

Modeling of the growth of the double layer was based on the model of Svoboda et al. (2006), assuming MgO is the only mobile component. This yields preliminary Arrhenius laws with activation energy E and pre-exponential factor D_0 for

- MgO diffusion in forsterite grain boundaries

$$E = 476 \pm 64 \text{ kJ/mol and } \log D_0 \text{ (m}^2\text{/s)} = 1.81 \pm 2.18$$

- MgO diffusion in enstatite grain boundaries

$$E = 521 \pm 70 \text{ kJ/mol and } \log D_0 \text{ (m}^2\text{/s)} = 3.32 \pm 2.39$$

when the grain boundaries width is assumed to be 1 nm. An easily observable consequence of the difference in these two laws is the variation of the forsterite/enstatite ratio, that increases when temperature decreases. Preliminary experiments have shown that kinetics are modified (enhanced) when the water content is higher. Thus, in addition to the determination of grain boundaries diffusion coefficient, multiphasic diffusion-reactions, such as metamorphic coronas, could be used as thermometers and indicators of water activity.

References: Svoboda, J., Gamsjäger E., Fischer, F. and Kozeschnik, E. (2006) Modeling of kinetics of diffusive phase transformation in binary systems with multiple stoichiometric phases. Journal of Phase Equilibria and Diffusion 27: 622-628