The kinetics of enstatite transformation under the subduction zone conditions

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Enstatite is one of the most abundant minerals in the Earth's upper mantle. It transforms to (modified) spinel plus stishovite, and to ilmenite at the depth of 500-600 km. Under subduction zone conditions, there is a possibility that these transformations are kinetically inhabited due to low temperatures (Hogrefe et al., 1994). But kinetics of high-pressure transformation of enstatite has never been examined quantitatively. In order to clarify kinetics of high-pressure transformation of enstatite, we performed in-situ X-ray diffraction experiments using SPEED-1500 multi-anvil high-pressure apparatus installed at SPring-8, Japan.

Starting material is powder of natural enstatite, (Mg0.99, Fe0.01)SiO3. The sample assembly is composed of ZrO2 and MgO pressure medium, rhenium heater, Mo and Au electrode, and graphite capsule. The starting material was annealed at 12-16 GPa and 1473K for 100 minutes in the stability field of high-pressure clinoenstatite or spinel plus stishovite, and then compressed to the desired pressure at 773K. Finally we heated the sample to the desired temperature at constant oil pressure with taking X-ray diffraction patterns every 10 seconds. In this way, we observed transformation kinetics from high-pressure clinoenstatite to ilmenite, from high-pressure clinoenstatite to spinel plus stishovite, and from spinel plus stishovite to ilmenite at 17.5-20.7 GPa and 1173-1773K.

At 20.1 GPa and 1363K, the enstatite-ilmenite transformation completed immediately in 10 seconds. At 20.0 GPa and 1273K, the transformation started in 40 seconds and completed in 180 seconds. At 19.8 GPa and 1223K, the transformation started in 110 seconds and did not complete in 40 minutes. On the other hand, the reaction rate from enstatite to spinel plus stishovite and from spinel plus stishovite started in 200 seconds and proceeded only by 30% in 220 minutes at 17.5 GPa, 1273K. The transformation of spinel plus stishovite to enstatite started in 120 seconds and proceeded only by 60% in 145 minutes at 20.7 GPa and 1773K. These transformations slowed down when the transformed fraction reached to 10% and 40%, respectively. This is probably because the growth in these transformations is diffusion controlled.

These results indicate that the decomposition of enstatite to spinel plus stishovite is slower than the enstatite-ilmenite transformation. It is likely that enstatite directly transforms to ilmenite in cold slabs. Furthermore, once enstatite decomposes into spinel plus stishovite in hot slabs, it might be rather difficult to transform to ilmenite.